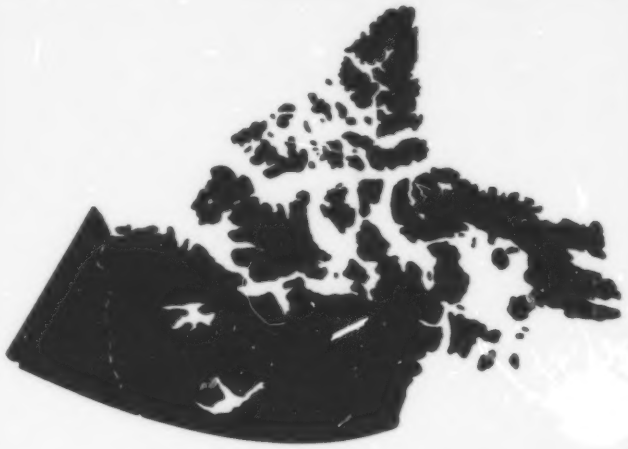


North of 60

An Approach to Monitoring Ambient Environmental Quality in the Slave River Basin, Northwest Territories:

Toward a Consensus

Indian and Northern Affairs Canada
Affaires indiennes et du Nord Canada

NWT REGION
RENEWABLE RESOURCES & ENVIRONMENT

An Approach to Monitoring Ambient Environmental Quality in the Slave River Basin, Northwest Territories: Toward a Consensus

by

D.D. MacDonald and S.L. Smith
MacDonald Environmental Sciences Ltd.
2376 Yellow Point Road, RR #3
Ladysmith, British Columbia
V0R 2E0

Prepared for

Water Resources Division
Renewable Resources and Environment
Indian and Northern Affairs Canada
Yellowknife, Northwest Territories
X1A 2R3

SPECIAL THANKS

An interagency steering committee of Yellowknife personnel was established to manage the Slave River Environment Quality Monitoring Program. To date this committee has been responsible for making available, from their agencies, the resources and personnel necessary for actual implementation of the components outlined in this report. Therefore, special thanks are extended to the following members of the steering committee and their staff in full knowledge that even more time, talent and energy will be necessary in fulfilling all components of this program:

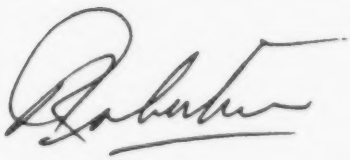
J. Letourneau, A/Regional Manager, Water Resources, DIAND

S. Lewis, Assistant Director, Renewable Resources, GNWT

R. Peet, Regional Director, Department of Fisheries and Oceans

A. Redshaw, Chief, Inland Waters Directorate, Conservation and Protection

The Renewable Resources and Environment Directorate of the Northern Affairs Program, N.W.T. Region would also like to express appreciation to the Natural Resources and Economic Development Branch, Northern Affairs Program Headquarters for the funding provided to produce this report.



A. Robertson
Director,
Renewable Resources and Environment
Northern Affairs Program
DIAND

Executive Summary

The territorial portion of the Slave River basin is a pristine watercourse which provides a host of benefits to Canadians, in general, and residents of the NWT, in particular. The system supports a variety of economically and sociologically important water uses. Specifically, the Slave River provides raw water for domestic water supply and an abundance of aquatic life that are essential to local area residents. Recreation is an emerging water use in the basin that has the potential to benefit residents and visitors to the area, alike.

Letourneau et al. (1988) recognized the need to maintain and improve environmental quality in the territorial portion of the Slave River basin. This assessment explicitly addressed the unique sensitivity of subsistence users to degradation of the quality of aquatic resources (both in the quality of water and fish flesh). An essential component of an effective management plan is an environmental quality monitoring program. The monitoring program should support assessment of compliance with environmental quality guidelines and objectives (applicable to water, sediment, and biota). In addition, the monitoring program should establish baseline conditions and identify trends in environmental quality. Identification of this need has sparked a number of initiatives which have been directed at the design and expedition of a comprehensive environmental monitoring program.

In June 1989, a workshop was held in Yellowknife to identify the basic elements of a monitoring program for the territorial portion of the Slave River. The major output of the workshop was an eight part program planning and management process designed to define the reconnaissance survey, research, and monitoring aspects of the Slave River program. This workshop represented the first attempt to develop a consensus on a monitoring program design for the Slave River basin and should be heralded for the depth and breadth of its findings and conclusions. However, while the explicit objectives of the workshop were achieved, the resulting monitoring program could not be easily implemented in its present form. A fundamental step towards narrowing the scope of that recommended monitoring program was to tie the implementation strategy to a well-defined set of program goals.

In February 1990, MacDonald (1990) prepared a discussion paper on the design of the Slave River environmental quality monitoring program. The monitoring program recommended in the discussion paper was specifically designed to address the questions that were most likely to be asked by water quality managers and the public.

These included: Is the water quality getting better or worse; Is the water safe to drink?; and, Are the fish safe to eat? MacDonald (1990) reasoned that water quality data would be of dubious value if these basic questions are not adequately answered.

On February 28 - March 1, 1990, more than twenty experts on aquatic environmental quality, representing territorial, federal, and provincial agencies and private sector interests, met in Edmonton to discuss the draft monitoring program design. The scope of the discussions were narrowed by asking Strategy Session participants to develop a practical, focused environmental quality monitoring program for the territorial portion of the Slave River basin, with an emphasis on the first year of the program. After two days of discussion, the Strategy Session participants arrived at a consensus on the design of the Slave River monitoring program.

The present report provides a framework for environmental quality monitoring in the Slave River by incorporating the suggestions from the Strategy Session into the draft monitoring program design recommended by MacDonald (1990). The resultant integrated multi-media monitoring program is designed to provide baseline data on levels of contaminants in water, suspended sediment, and biota in the territorial portion of the Slave River basin. As such, the monitoring program design provides recommendations on the location of sampling sites, sampling frequency, sampling methods, sample archiving, and quality assurance/quality control. In addition, a complete listing of variables which should be measured in each environmental compartment (ie. water, suspended sediment, and biota) is provided.

Table of Contents

Executive Summary i

Table of Contents iii

List of Tables viii

Acknowledgements ix

Chapter 1

Monitoring Environmental Quality in the Slave River Basin: An Introduction 1

Chapter 2

Monitoring Environmental Quality in the Slave River Basin: Evolution of the Integrated Multi-Media Program 3

Chapter 3

Monitoring Environmental Quality in the Slave River Basin: Historical and Ongoing Activities 6

3.0 Introduction 6

3.1 Environment Canada 6

3.1.1 Long-term Water Quality Monitoring Network 6
3.1.2 National Water Research Institute (PERD) Study . . 7
3.1.3 Wood Buffalo National Park Monitoring Program . . . 8

3.2 Alberta Environment 9

3.3 British Columbia Ministry of Environment 10

3.4 Athabasca Chipewyan Band. 10

Chapter 4

A Theoretical Perspective on Environmental Quality Monitoring: Goals and Objectives 11

4.0 Introduction 11

4.1 Monitoring for Assessment of Compliance with Environmental Quality Objectives 11

4.2 Monitoring for Assessment of Trends 12

4.3 Monitoring for Estimation of Mass Transport 13

4.4 Monitoring for Assessment of Environmental Impacts 13

Chapter 5

The Slave River Integrated Multi-Media Monitoring Program: Goals and Objectives 15

5.0 Introduction 15

5.1 Water Management Goals in the NWT 15
5.1.1 Protection of Drinking Water Supplies 15
5.1.2 Protection of Subsistence Users 16
5.1.3 Northern Ecosystem Protection 17

5.2 Objectives of the Slave River Basin Monitoring Program 18

Chapter 6

The Slave River Integrated Multi-Media Monitoring Program: Quality Assurance/Quality Control 20

6.0 Introduction 20

6.1 Field Sampling and Laboratory Procedures 20

6.2 Data Management Procedures 22

Chapter 7

The Slave River Integrated Multi-Media Monitoring Program: Water 24

7.0 Introduction 24

7.1 Potential Sampling Locations 24

7.2 Station Evaluation 25

7.3 Priority Water Quality Variables 26
7.3.1 General Variables 27
7.3.2 Anions 27
7.3.3 Pesticides 27
7.3.4 Organochlorines 27
7.3.5 Polynuclear Aromatic Hydrocarbons 28
7.3.6 Other Organic Compounds 28
7.3.7 Other Variables 28

7.4 Sampling Frequency 28

7.5 Sampling Methods 29

7.6 Sample Preparation and Archiving 30

7.7 Quality Assurance and Quality Control 31

Chapter 8

The Slave River Integrated Multi-Media Monitoring Program: Suspended Sediment 32

8.0 Introduction 32

8.1 Potential Sampling Locations 32

8.2 Priority Variables for Suspended Sediment Monitoring 33
8.2.1 General Variables 33
8.2.2 Metals 33
8.2.3 Pesticides 34
8.2.4 Organochlorines 34
8.2.5 Polychlorinated Biphenyls 34
8.2.6 Polynuclear Aromatic Hydrocarbons 34
8.2.7 Other Organic Compounds 35

8.3 Sampling Frequency 35

8.4 Sampling Methods 35

8.5 Sample Preparation and Archiving 36

8.6 Quality Assurance and Quality Control 37

Chapter 9

The Slave River Integrated Multi-Media Monitoring Program: Biota 38

9.0 Introduction 38

9.1 Potential Monitoring Species and Locations 39

9.2 Priority Variables for Biological Monitoring . . . 42
9.2.1 General Variables 42
9.2.2 Metals 42
9.2.3 Pesticides 42
9.2.4 Organochlorines 43
9.2.5 Polychlorinated Biphenyls 43
9.2.6 Polynuclear Aromatic Hydrocarbons 43
9.2.7 Other Organic Compounds 43

9.3 Sampling Frequency and Timing 44

9.4 Sampling Methods 44

9.5 Sampling Preparation and Archiving 45

9.6 Quality Assurance and Quality Control 46

Chapter 10

The Slave River Trend Assessment Monitoring Program: Identification of Indicators of Ecosystem Health 47

10.0 Introduction 47

10.1 Monitoring for Trend Assessment 48

10.2 Potential Monitoring Compartments for Biotrend Assessment 49
10.2.1 Bed Sediments 49
10.2.2 Algae 50
10.2.3 Aquatic Mosses 50
10.2.4 Rooted Aquatic Plants 51
10.2.5 Benthic Invertebrates 51
10.2.6 Fish 54

10.3 Criteria for the Selection of Indicator Species . . 54

10.4 Reconnaissance Study To Evaluate Potential Indicator Species 55

10.5 Priority Variables for Biological Monitoring for Trend Assessment 56
10.5.1 General Variables 56
10.5.2 Nutrients 56
10.5.3 Metals 57
10.5.4 Insecticides 57
10.5.5 Herbicides 57
10.5.6 Organochlorines 57
10.5.7 Polychlorinated Biphenyls 57
10.5.8 Polynuclear Aromatic Hydrocarbons 57

10.6 Design of the Trend Assessment Monitoring Program . 57

11.0 References 59

List of Tables

Table 1	Annual Domestic Water Use in the Territorial Portion of the Slave River Basin.	16
Table 2	Estimated Average Annual Harvest of Fish Species in the Slave River Domestic Fishery by Area	17
Table 3	Sources of Variability in Water Quality Data . . .	26
Table 4	Assessment of the Suitability of Fish Species in the Slave River for Inclusion in a Biomonitoring Program	40
Table 5	Summary of Information used to Score Attributes of Fish Species in the Slave River Basin	41
Table 6	Potential Benthic Biomonitoring Organisms for the Slave River Integrated Monitoring Program . . .	53

Acknowledgements

It would be difficult to explicitly acknowledge all of the persons who contributed to the production of this report. However, the authors would like to gratefully acknowledge those persons who contributed significantly to its preparation. Literature searches were undertaken by S. Smith, C. Neer, C.P. Newcombe and M. Johnson. Unpublished data and information were kindly provided by B. Grey, J. Letourneau, B. Kemper, D. Trew, R. Bourbonniere, J. Peddle, D. Donald, and B. Crosley. M.L. Haines was also instrumental in the final preparation of the present draft.

The authors would also like to express their most sincere gratitude to all of the experts who participated in the NWT Slave River Environmental Quality Monitoring Strategy Session. B. Munsen deserves special thanks for chairing the Strategy Session and keeping the discussions focused and on track. Strategy Session participants included:

Name	Affiliation
D. Birkholz	Envirotest Labs, Edmonton
W. Coedy	Indian and Northern Affairs Canada, Yellowknife
D. Donald	Environment Canada, Regina
B. Grey	Indian and Northern Affairs Canada, Yellowknife
S. Harbicht	Fisheries and Oceans Canada, Yellowknife
M. Jones	Environment Canada, Fort Smith
C. Katopodis	Fisheries and Oceans Canada, Winnipeg
B. Kemper	Alberta Environment, Edmonton
R. Kent	Environment Canada, Ottawa
J. Letourneau	Indian and Northern Affairs Canada, Yellowknife
L. Lockhart	Fisheries and Oceans Canada, Winnipeg
D. MacDonald	MacDonald Environmental Sciences Ltd., Vancouver
B. Munsen	Environment Canada, Edmonton
E. Ongley	Environment Canada, Burlington
J. Peddle	Environment Canada, Yellowknife
A. Redshaw	Environment Canada, Yellowknife
A. Robertson	Indian and Northern Affairs Canada, Yellowknife
K. Robertson	GNWT Dept. of Renewable Resources, Yellowknife
D. Rosenberg	Fisheries and Oceans Canada, Winnipeg
S. Smith	MacDonald Environmental Sciences Ltd., Vancouver
W. Starling	Indian and Northern Affairs Canada, Fort Smith
R. Stevens	Environment Canada, Ottawa
D. Sutherland	Environment Canada, Yellowknife
M. Whittle	Fisheries and Oceans Canada, Burlington
R. Wickstrom	Environment Canada, Winnipeg

Chapter 1

Monitoring Environmental Quality in the Slave River Basin: An Introduction

The territorial portion of the Slave River basin drains an area of 2,252 km^2. From the Rapids of the Drowned in the vicinity of Ft. Smith, the river flows approximately 320 km in a north - northwesterly direction to Great Slave Lake. Over that distance, the Slave is joined by several tributaries, the most significant of these being the Salt River.

Designated water uses in the Northwest Territories (NWT) include those involving domestic water supplies, recreation and aesthetics, fish and aquatic life, agriculture, and industrial supplies (process water). Of these, instream water uses (fish and aquatic life) are at the forefront of management policy in the territorial portion of the Slave River basin, due to their importance to local area residents and due to their influence on other water uses (ie. recreation and aesthetics). In addition, the majority of residents in the area depend on the Slave River, or waters whose quality is affected by the Slave River, for their raw water supply.

In addition to the beneficial uses of water in the Northwest Territories, domestic, agricultural, and industrial waste products are released into the Slave River basin by upstream jurisdictions (British Columbia and Alberta) . Inputs of sewage and other domestic wastes, herbicides and other pesticides, heavy metals, and other toxic compounds tend to contaminate water resources and, in so doing, have had the potential to compromise downstream water uses.

The long-range outlook for the Slave River basin includes additional demands on its water resources. Large-scale expansion of the forest products industries will, undoubtedly, result in the use of water resources within the Slave River basin for the disposal of toxic organic chemicals, such as chlorophenols and dioxins. This rapid expansion of the pulp and paper industry in British Columbia and Alberta is eclipsing our ability to assess cumulative impacts on downstream water uses. With expansion of the tar sands mining operations imminent, the potential for the release of toxic and tainting compounds into stream systems is further increased. Non-point sources of pollution arising from agricultural and forest management activities, including inputs of pesticides and nutrients, are superimposed on those sources that are more quantifiable.

This rapid expansion of the industrial sectors in Alberta and British Columbia has lead to serious doubts and public debates about the overall benefits of these proposed developmental activities to Canadians. Realization of the risks (real and

perceived) associated with ingestion of toxic chemicals has resulted in an increased level of concern over the purity of drinking water, particularly among groups that draw their raw water supplies directly from surface waters within the basin. In addition, the potential for contamination of fisheries resources with toxic organic compounds has been recognized, most graphically, with the recent fisheries closures in the vicinity of pulpmills in British Columbia. Of particular concern to water managers and the public is that native peoples may be more sensitive to toxic organic contaminants in fish tissues if their diets include high intake rates of fish and especially if internal organs (which generally have higher levels of pollutants than muscle tissues) are utilized.

In the Northwest Territories, maintenance and enhancement of the existing high quality fisheries and aquatic resources have been identified as high priority, long-term goals. In addition, recreation is an emerging water use that will require more consideration in the future, particularly in areas like Wood Buffalo National Park which have abundant tourism potential. Protection and conservation of territorial interests will necessarily require: a) development and implementation of site-specific environmental quality objectives to guide developmental activities; b) long-term monitoring to detect changes in environmental quality, and; c) remedial action if the results of environmental monitoring indicate that anthropogenic developments in upstream areas have lead to detrimental changes in environmental quality in the territorial portion of the Slave River basin.

Water quality objectives for the transboundary portion of the Slave River, formulated on site-adapted or site-specific bases, will provide a framework for making scientifically and economically defensible decisions on how water resources ought to be used throughout the river basin. Scientifically based transboundary water quality objectives will provide use protection within the NWT without unduly restricting developmental activities in upstream jurisdictions.

This report is designed to provide a framework for the implementation of a comprehensive environmental quality monitoring program on the Slave River. The recommended program has two major components; monitoring for compliance with environmental quality guidelines and monitoring for assessment of trends in environmental quality. In addition, the recommended program will provide information with which to establish baseline environmental quality conditions in the river basin. As such, the recommended program encompasses a multi-media monitoring design strategy (MacDonald 1990) and incorporates the results of the Strategy Session on the Slave River Monitoring Program (held in Edmonton, Alberta on February 28 - March 1, 1990). The transboundary water management agreement between Alberta and the Northwest Territories, which is currently under negotiation, may require the development of another component of the monitoring program to assess compliance with environmental quality objectives.

Chapter 2

Monitoring Environmental Quality in the Slave River Basin: Evolution of the Integrated Multi-Media Program

The territorial portion of the Slave River basin is a pristine watercourse which provides a host of benefits to Canadians, in general, and residents of the NWT, in particular. The system supports a variety of economically and sociologically important water uses. Specifically, the Slave River provides raw water for domestic water supply and an abundance of aquatic life that are essential to local area residents. Recreation and aesthetics is an emerging water use in the basin that has the potential to benefit residents and visitors to the area, alike.

Letourneau et al. (1988) recognized the need to maintain and improve environmental quality in the territorial portion of the Slave River basin. This assessment explicitly addressed the unique sensitivity of subsistence users to degradation of the quality of aquatic resources (both in the quality of water and fish flesh). An essential component of an effective management plan is an environmental quality monitoring program to establish baseline conditions and identify trends in environmental quality. Identification of this need for a comprehensive environmental monitoring program has sparked a number of initiatives that have been directed at its design and expedition.

In June, 1989 a workshop was held in Yellowknife to identify the basic elements of a monitoring program for the territorial portion of the Slave River. A report was published on the findings and conclusions of the Slave River water quality monitoring workshop (Dominion Ecological Consulting Ltd. and RMC Resources Management Consultants Ltd.; DECL and RMC 1989). This report provided a summary of the objectives of the workshop, which are presented here to provide a context for the workshop findings and conclusions.

The objectives of the workshop were to make recommendations on the design of a program to monitor water and the living environment it supports, focusing on:

(a) end-use requirements such as in-stream uses (aquatic life), human consumptive use of resources (fish and water), and non-consumptive uses (parks);

(b) features of the program, such as the capability to provide early indications of ecosystem stress and change, accommodate future changes as scientific knowledge and analytical techniques evolve, distinguish between sources of changes using indicator species and program components, address

> the significance of changes resulting from upstream development in relation to future protection programs, contain a research and reconnaissance phase, be sensitive to qualitative and quantitative measures of ecosystem components, and, assist the process of defining water quality standards and objectives.

Two specific tasks were subsequently identified to respond to the workshop goal and objectives. The first task was to define a program approach to look for, and to find, changes and stresses resulting from pulp mill effluents and oil and gas developments. The second task was to determine methods to detect stresses on, and changes in, the Slave River basin as a whole, including stresses that might be induced by activities such as agriculture, hydroelectric developments, and human settlement (DECL and RMC 1989).

The major output of the workshop was an eight part program planning and management process designed to define the reconnaissance survey, research, and monitoring aspects of the Slave River program. This process was thought to be self-adjusting and self-regulating, which would permit various aspects of the program to be modified according to need and the kinds of changes in water quality detected in the course of monitoring. It was also deemed to be cost-effective and scientifically accountable, since program needs would drive related research, and not vice versa (DECL and RMC 1989).

This workshop represented the first attempt to develop a consensus on a monitoring program design for the Slave River basin and should be heralded for the depth and breadth of its findings and conclusions. However, while the explicit objectives of the workshop were achieved, the resulting monitoring program could not be easily implemented in its present form. A fundamental step towards narrowing the scope of that recommended monitoring program was to tie the implementation strategy to a well-defined set of program goals.

MacDonald (1990) suggested that the Slave River environmental quality monitoring program should be designed to specifically address the questions that are likely to be asked by water quality managers and the public. The most common of these are; a) is the water quality getting better or worse?, b) is the water safe to drink?, and, c) are the fish safe to eat? Water quality data will be of dubious value if these basic questions are not adequately addressed.

MacDonald (1990) recommended a strategic approach to monitoring environmental quality conditions in the Slave River basin. This approach called for establishment of a comprehensive assessment of baseline environmental quality conditions prior to the expansion of developmental activities. While the nature and extent of industrial, agricultural, and other activities in upstream jurisdictions precludes the development of a true pre-developmental baseline for the Slave River, an opportunity exists to establish a pre-developmental expansion baseline. This baseline would, then, provide a basis for determining the direction and magnitude of environmental quality shifts over time.

The other major focus of the recommended Slave River monitoring program was to establish the risks associated with consumption of aquatic resources. Risk assessment requires information on the sensitivities of the species likely to be affected (ie. humans, white pelicans, mink, etc.) by environmental contamination (usually measured as the maximum intake of a substance on a daily basis). In addition, information is also required on the concentrations of contaminants in water, sediment, and biota, and on the temporal and spatial variability of these levels. The recommended program was designed to provide the information required to evaluate these risks.

MacDonald (1990) was then used as a discussion paper at the Strategy Session on the Slave River Monitoring Program held in Edmonton on February 28 and March 1, 1990. The two day session, attended by experts representing a variety of federal, territorial, and provincial agencies and private sector interests, resulted in a number of recommendations on the design of the monitoring program. These recommendations explicitly applied to the first year of the study plan, but many may also be applicable to subsequent years.

The present report provides a framework for environmental quality monitoring in the Slave River by incorporating the suggestions from the Strategy Session into the draft monitoring program design recommended by MacDonald (1990). The resultant integrated multi-media monitoring program is designed to provide baseline data on levels of contaminants in water, suspended sediment, and biota in the territorial portion of the Slave River basin. As such, the monitoring program design provides recommendations on the location of sampling sites, sampling frequency, sampling methods, sample archiving, and quality assurance/quality control. In addition, a complete listing of variables which should be measured in each environmental compartment (ie. water, suspended sediment, and biota) is provided.

Chapter 3

Monitoring Environmental Quality in the Slave River Basin: Historical and Ongoing Activities

3.0 Introduction

Water quality monitoring activities in the Slave River basin were initiated in 1960 with the implementation of monitoring stations on the Peace, Athabasca, and Slave Rivers. Since that time, water quality data have been collected on nearly every watercourse within the river basin. Early monitoring efforts were largely focused on determination of concentrations of inorganic variables in water and were orchestrated by Environment Canada. In addition, Indian and Northern Affairs Canada have been sampling water quality (major ions, metals, and nutrients) in the Slave River at Fort Smith and Slave River at the mouth (two times per year) since 1982. More recently, special studies and more comprehensive monitoring have been undertaken by a variety of interests within the basin, including federal agencies, provincial agencies, native groups, municipal governments and industrial interests. The resulting database of environmental quality data covers a broad geographic area and a wide range of variables.

The following sections provide a brief overview of historical and ongoing monitoring activities within the river basin. Consideration of these monitoring efforts will increase the likelihood that data collected in the territorial portion of the basin will be compatible with and comparable to data collected elsewhere in the basin.

3.1 Environment Canada

3.1.1 Long-term Water Quality Monitoring Network

The Water Quality Branch has historical records of water quality conditions at approximately 350 stations within the Slave River basin. For most of these stations the period of record is fairly short (usually 4 - 5 years) covering the early to mid 1970's. At these sites, the database consists of information on physical variables, nutrients, major ions, and to a lesser extent metals and trace elements in water. Few data exist on pesticide levels, and almost no data exist on other chemicals of industrial origin.

A total of eight stations have been designated as long-term monitoring stations. These stations are operated, either formally or informally, as federal - provincial or federal - territorial stations, in conjunction with Alberta Environment, British Columbia Ministry of Environment, and the Government of the Northwest Territories. These sites include:

a) Peace River U/S Alces River,
b) Peace River at Dunevegan,
c) Peace River at Ft. Vermillion,
d) Smoky River at Watino,
e) Athabasca River at Jasper,
f) Athabasca River at Athabasca,
g) Athabasca River at Old Fort, and
h) Slave River at Fitzgerald (co-funded by Alberta Environment and the Government of the Northwest Territories).

At these sites, long-term monitoring is focused on major ions, physical variables, nutrients, bacteriological variables, metals and metalloids. Measurements are made monthly for the majority of these variables; extractable metals, PCBs and selected pesticides are measured on quarterly bases.

3.1.2 National Water Research Institute (PERD) Study

In 1989, the Rivers Research Branch of the National Water Research Institute (NWRI) initiated a five year study on the transport, fate and effects of polycyclic aromatic hydrocarbons (PAHs) and related compounds in the Athabasca River basin. The NWRI study is sponsored by the Panel for Energy Research and Development (PERD) and focuses on the reach of the river from Ft. McMurray to Wood Buffalo National Park.

The objectives of the NWRI study are to identify the specific PAHs present in the aquatic environment, to determine the persistence and fate (including pathways of distribution and transformation) of these compounds, and to determine their effects on organisms at various trophic levels. In addition, a predictive model applicable to the organic contaminants present in the system is to be generated. The results of this study will be used to evaluate the environmental impacts of hydrocarbon extraction developments within the river basin.

An initial reconnaissance survey was conducted in July - August, 1989 to evaluate spatial variability in contaminant concentrations in a variety of media types. Water (large volume extracts), suspended sediments, bed sediments, and fish (liver, bile, and muscle) were collected at four sites within the study area, including:

a) Athabasca River at Ft. McMurray,
b) Athabasca River at Mile 16,
c) Athabasca River at Ft. MacKay, and
d) Athabasca River at Mile 73.

It is anticipated that similar surveys will be undertaken twice a year (during late summer conditions at low flow and during winter conditions under ice cover) over the next three years (B. Crosley, Water Quality Branch, Calgary, Alberta. Personal Communication).

3.1.3 Wood Buffalo National Park Monitoring Program

In addition to the long-term monitoring network and the NWRI study, Environment Canada (Inland Waters and Parks Canada) has designed and implemented the Wood Buffalo National Park water quality monitoring program. Water quality monitoring, per se, was initiated in June of 1989 at two sites within the Slave River basin:

a) Peace River at Peace Point, and
b) Athabasca River at 27 Baseline (above Embarras River).

This program has a planned duration of at least five years, with the potential for modification of the duration and/or content of the program based on monitoring results, research recommendations, data from upstream locations, and future trends in developmental activities. At present, sampling is conducted on a monthly basis and addresses major ions, physical variables, nutrients, and metals.

The second phase of this program was designed, in coordination with National Waters Research Institute, to address contamination of aquatic ecosystems with selected organic constituents. Multi-media sampling was initiated at three sites in the Slave River basin in August of 1989:

a) Peace River at Peace Point,
b) Athabasca River at 27 Baseline (above Embarras River), and
c) Slave River at Fitzgerald.

Two sampling periods, August 1989 and February 1990, were explicitly identified for conducting survey activities in support of this program. Sampling media include water (large volume extracts), suspended sediment, bed sediment, and fish (usually goldeye). Target variables in this component of the program are an array of PAHs and related compounds, such as would be expected from tar sands mining operations. In addition, mixed function oxidase (MFO) enzyme activity, furans, and dioxins are measured in most fish samples. Future sampling activities may also address a variety of organic contaminants associated with the pulp and paper industry (B. Crosley, Water Quality Branch, Calgary, Alberta. Personal Communication).

3.2 Alberta Environment

Alberta Environment maintains a network of medium-term stations, in addition to the long-term monitoring stations operated under the federal - provincial agreement, throughout the portion of the Slave River basin lying within Alberta. These stations are used to establish baseline conditions, detect changes in water quality through time and space, and assess compliance with water quality objectives.

Alberta Environment has, and will continue to, conduct(ed) intensive investigations in the vicinity of major industrial developments. These efforts are focused on establishing pre-developmental expansion baseline conditions at locations which may be impacted by industrial expansion. Further, monitoring activities at these stations will continue through the developmental period to assess environmental impacts. The variables measured at these locations will be selected based on the nature of the proposed development (Alberta Environment 1989).

There are a total of ten mainstem, ten tributary, and five effluent medium-term water quality monitoring stations in the Peace River basin. At these locations, samples are taken monthly during open water and twice in the winter. Variables measured at these stations include physical variables, major ions, suspended solids, nutrients, metals, pesticides, and a variety of volatile and semi-volatile organic compounds. In addition, bacteriological and other biological variables are measured.

In the Athabasca River basin, Alberta Environment has maintained long-term, fixed monitoring stations at Jasper, Athabasca and Old Fort (now part of the federal - provincial monitoring network). At these stations, a variety of physical, chemical, and biological variables are measured including temperature, pH, conductivity, dissolved oxygen, major ions, suspended solids, nutrients, metals, and pesticides.

In addition to the long-term and medium-term monitoring programs, Alberta Environment has undertaken a number of special studies of ambient water quality conditions, including the Alberta Oil Sands Environmental Review Program (AOSERP 1975 - 85), the Athabasca Water Quality Overview (1984 - 85), and the Delta Survey (1987 - 1989). In addition, an integrated program of synoptic surveys was implemented, during the fall and winter of 1988 - 89, on the Athabasca River from Hinton to Lake Athabasca. This program consisted of a number of components, including hydraulics surveys, winter water quality surveys, characterization of effluent quality, fixed site and continuous monitoring, re-aeration investigations, and a sediment oxygen demand study. The results of this study provided a comprehensive database on winter water quality in the Athabasca River (Alberta Environment 1989).

Future monitoring activities in Alberta will include maintenance of the long-term monitoring stations, implementation of six additional medium-term monitoring stations (frequency = 7 times per year) in the vicinity of pulpmill developments, intensive pre-and post-development monitoring downstream of new pulpmills, and annual winter surveys of ambient water quality and effluent quality from Hinton to Lake Athabasca. These surveys will focus on a comprehensive suite of variables, including dissolved oxygen (continuous monitoring during winter conditions at key stations) and a variety of volatile and semi-volatile organic compounds. In addition, bacteriological and other biological variables will be measured.

3.3 British Columbia Ministry of Environment

British Columbia Ministry of Environment (BCMOE), in conjunction with Environment Canada, operates one long-term monitoring station in the Peace River drainage basin under the Federal - Provincial Monitoring Agreement. This site is located upstream of the Alces River (approximately 3 km from the provincial boundary).

In addition, BCMOE has historical records of water quality conditions at over forty sites on the Peace River mainstem and tributaries. These data are focused on general water quality variables, metals, nutrients, and bacteriological characteristics. At some sites, data exists on dissolved gases, phenols, cyanide, and other variables, reflecting the anticipated inputs from upstream developments (Butcher 1987).

The bulk of the water quality monitoring effort supported by BCMOE is currently directed at monitoring for compliance with water quality objectives. Monitoring for compliance is undertaken at nine stations on tributaries to the Peace River and at six stations on the Peace River mainstem. The sampling frequency at these stations is generally five or fewer times per year (Water Management Branch 1989).

3.4 Athabasca Chipewyan Band

The Athabasca Chipewyan Band has initiated a study to determine the extent of contamination of selected perched lakes in the Athabasca Delta. This study (Crowther et al., 1990) specifically focused on pollutants originating from municipal and industrial sources. The program was designed to sample bed sediments in three artificially controlled perched lakes on the Chipewyan Reserve Number 201. Two of these lakes were connected to the Athabasca River (the presumes source of contamination) and the other lake was used as a control. These lakes are flooded during spring freshet, and have the potential to concentrate contaminants during the post-flood season (B. Crosley, Water Quality Branch, Calgary, Alberta. Personal Communication).

Chapter 4

A Theoretical Perspective on Environmental Quality Monitoring: Goals and Objectives

4.0 Introduction

Aquatic environmental quality monitoring encompasses an array of activities that are designed to provide information on the physical, chemical, and biological characteristics of water. In practice, these activities include both routine monitoring programs (ongoing) and special surveys (one time) which are undertaken in support of water quality management. It is now universally recognized that monitoring is indispensable for rational and effective management of aquatic resources (Ward et al. 1986). However, a fundamental problem associated with many ongoing monitoring programs is the lack of a well defined monitoring strategy (Whitfield 1988). To be effective, a monitoring program must have a well defined purpose and must support water quality management (Ward 1979; Schilperoort and Groot 1983).

The main reasons for conducting environmental quality monitoring programs include: i) assessment of compliance with environmental quality objectives; ii) trend assessment; iii) estimation of mass transport; and, iv) environmental impact assessment (Whitfield 1988). As definition of the reason for monitoring is a fundamental component of the monitoring program, it is important to understand each of the four general approaches to environmental quality monitoring. Therefore, the following sections are devoted to explicitly defining these monitoring strategies in support of the development of specific monitoring goals for the Slave River program.

4.1 Monitoring for Assessment of Compliance with Environmental Quality Objectives

Environmental quality objectives are numerical concentrations or narrative statements which have been established, through some unilateral or interjurisdictional mechanism (ie. International Joint Commission, Prairie Provinces Water Board; Bilateral Committees, etc.), to support and maintain the designated uses of water at specific locations or stream reaches. Environmental quality guidelines and standards are similar in nature to environmental quality objectives, but differ in their application and enforceability (see Canadian Council of Resource and Environment Ministers 1987 for a complete set of definitions of these water management tools).

The goal of compliance monitoring is to determine whether or not the objectives set for quality are being met (Whitfield 1988). Monitoring for compliance with environmental quality objectives is complicated by the inherent variability of the system in space and time and by the way in which the objectives are written. For example, specific objectives may be written as maximum, arithmetic mean, geometric mean, and/or median values (to mention a few) over a particular period of time. The effectiveness of compliance monitoring programs is often expressed as the ratio of detected violations to actual violations of the objective (Schilperoort and Groot 1983). The most appropriate sampling strategies for use in compliance monitoring programs are those which have high effectiveness to cost ratios.

4.2 Monitoring for Assessment of Trends

Trends in environmental quality can result from both natural processes and anthropogenic activities. Trends resulting from natural processes generally occur over extended time scales, while trends associated with human activities usually occur more quickly. The objective of trend monitoring is to collect data that will facilitate the assessment of short- and long-term trends in environmental quality conditions (Whitfield 1988). A cornerstone of this strategy is the establishment of a set of baseline conditions against which the results of future monitoring activities may be compared.

Trend assessment provides a means of identifying changes in environmental quality over time, and therefore a means of identifying situations that are becoming or have become problematic. This monitoring strategy (when used in conjunction with environmental quality guidelines) can be used to identify situations that require remedial action and to assess the effectiveness of any remedial actions that are undertaken. These types of monitoring programs must explicitly recognize the various factors that can affect environmental quality and be designed to identify the sources of these effects. In general, the method used for distinguishing trends associated with natural processes from those related to human activities involves the incorporation of reference stations into the program design. In addition, ancillary data should be collected on the nature and extent of developmental activities, on precipitation, on stream discharge, and on other variables to facilitate cause and effect evaluations.

4.3 Monitoring for Estimation of Mass Transport

The amount of a material that is carried by a river over a specified period of time is termed the load. Information on contaminant loadings (mass transport) is used in a number of applications, including calculation of reservoir sedimentation rates (suspended sediment) and predicting algal responses in lakes (nutrients). Contaminant loadings are calculated from river discharge rates and concentrations of the material under consideration. Accurate estimation of contaminant loadings requires comprehensive information on the relationship between these two variables. In this way, information on streamflows may be used, in conjunction with concentration data, to estimate contaminant loadings.

The concentrations of many water quality variables are dependent on stream discharge. The concentrations of water borne substances may be independent of flow under controlled flow conditions and/or when effluent discharges are the major sources of the contaminant. For flow dependent variables, concentrations may either increase or decrease with increasing flow. Monitoring strategies adopted to address estimation of mass transport must be designed to detect and define concentration variations over time. Where concentrations are dependent on flow, monitoring programs should be designed to representatively sample over the entire range of streamflows (Yaksich and Verhoff 1983). Where concentrations are independent of flow, random sampling or stratified sampling is the most appropriate. An important assumption in the estimation of mass transport of a water borne substance is that the measured concentrations accurately reflect the actual concentrations during periods of time that are not sampled (Whitfield 1982). Therefore, the accuracy with which the behaviour of the chemical is defined determines, to a large degree, the accuracy of the load estimate.

4.4 Monitoring for Assessment of Environmental Impacts

Environmental impact assessment requires a special monitoring strategy that is designed to differentiate among variations in environmental quality associated with natural processes, with sampling procedures, and with human activities (Lettenmaier et al. 1978). A cornerstone of this approach involves the accurate evaluation (ie. impacts) of the environmental quality changes that are likely to occur as a result of specific activities. In this way, monitoring efforts can be focused on appropriate priority variables and time periods. The essential component of the impact assessment monitoring strategy is an adequate control (Valiela Ward 1978). There are a variety of controls that may be used for this type of monitoring, including reference sites in unaffected systems, control sites located upstream of the disturbance, and downstream sites for which pre-developmental (baseline) conditions have been defined.

Successful monitoring for assessment of environmental impacts also requires implementation of sampling strategies that facilitate comparison of data generated at control and affected sites. The frequency and timing of sampling at the various sites are fundamental considerations for monitoring programs designed to assess environmental impacts. For example, time series analysis is best suited to data sets developed using fixed frequency sampling (Hipel 1985). In addition, the design of the monitoring program should consider the statistical methods that will be used for analyzing the data set on an *a priori* basis. In many cases, the minimum number of samples required to detect changes in environmental quality is definable at the outset. For example, intervention analysis may require at least 50 samples to measure all but very large shifts in environmental quality (Lettenmaier et al. 1978). Further, monitoring programs focused on impact assessment should be broad, and yet sensitive enough to detect changes in the concentrations of a wide variety of variables, not just the ones with the highest likelihood of being affected (Valiela Ward 1978).

Chapter 5

The Slave River Integrated Multi-Media Monitoring Program: Goals and Objectives

5.0 Introduction

The previous sections described several of the approaches to the development of environmental quality monitoring programs that could be applicable to the Slave River basin. Careful examination reveals that each of these approaches provide data sets that are applicable to the specific goal associated with the monitoring program. In addition, it is apparent that a data set collected for one purpose (ie. assessment of compliance with environmental quality objectives) can not necessarily be used to address other monitoring goals (ie. trend assessment). Therefore, the first step in the design of a monitoring program for the Slave River must be to define the goal or goals of the monitoring program. In order to define the goals of the monitoring program, it is first necessary to examine the objectives with respect to the management of aquatic resources in the NWT.

5.1 Water Management Goals in the NWT

Letourneau et al. (1988) provided an assessment of NWT interests and needs with respect to water management issues. These authors indicated that protection of northern ecosystems is the most important concern in transboundary water management. In addition, the unique sensitivity of subsistence users to changes in the natural environment (ie. in water and/or fish flesh quality) was explicitly addressed. Further, tourism was identified as a growth industry in the NWT and it was noted that water uses associated with tourism (ie. sport fishing, recreation and aesthetics) are strongly affected by environmental degradation, both real and perceived. Therefore, a clear, long-term goal of water managers in the NWT is to maintain the existing superior environmental quality conditions in the territorial portion of the Slave River basin.

5.1.1 Protection of Drinking Water Supplies

Good quality water, in adequate supply, is a basic human need. In the territorial portion of the basin, water originating in the Slave River basin provides most of the drinking water that is consumed by area residents (Table 1). Degradation of water quality in the Slave River could result in unacceptable drinking water quality at existing levels of treatment. This, in turn, could necessitate additional treatment prior to use or development of alternate water sources, at substantial costs to local area residents and/or

territorial regulatory agencies. Therefore, protection of existing domestic water supplies is a high priority water management goal within the NWT.

Table 1. Annual domestic water use in the territorial portion of the Slave River basin.[1]

Community	Water Source	Volume(m^3)	Year
Fort Smith	Slave River	333,102	1988
Fort Resolution	Great Slave Lake	15,500	1988
Hay River	Great Slave Lake	393,203	1988
Fort Providence	Mackenzie River	19,000	1988-89

1. Source: Water Resources Division , Indian and Northern Affairs Canada, Yellowknife, NWT. The communities on Great Slave Lake and the MacKenzie River are considered here due to the large effect of the Slave River on the water quality of these nearby downstream areas.

5.1.2 Protection of Subsistence Users

Upstream developmental activities have the potential to contribute vast quantities of organic and inorganic contaminants to aquatic ecosystems within the Slave River basin. Downstream transport and subsequent bioaccumulation of these contaminants can result in unsafe levels in edible fish flesh. Bioaccumulation of industrial and/or agricultural contaminants may have major human health and economic implications when it occurs in species that are harvested in commercial or subsistence fisheries.

Residents within the Slave River basin rely on subsistence (domestic) fisheries to provide a portion (in some cases, a substantial portion) of their metabolic energy requirements (RL&L and EMA Slave River Joint Venture 1985). In addition, large quantities of fish are routinely obtained from the Slave River for use as dog food by area residents (Table 2). Therefore, a second, high priority water management goal involves the protection of subsistence users by evaluating the fish that are caught within the basin.

Table 2. Estimated average annual harvest of fish species in the Slave River domestic fishery by area (adapted from RL&L and EMA Slave River Joint Venture 1985).

Species	Estimated Catch (kg) by Area[1]					Major Use[2]
	ROD	CL	SR	SRD	Total	
Inconnu	16,000	2,000	800	250	19,000+	Dog
Lake Whitefish	13,000	1,000	100	50	14,100+	Dog/ Human
Goldeye	750	150	5+	5+	900+	Dog
Northern Pike	1,500	250	10+	150	1,900+	Dog
Walleye	300	500	10+	10+	800+	Human
Suckers	2,000+	500	20+	10+	2,500+	Dog
Burbot	unknown	5,300	1,000	220	6,500+	Human

1. ROD = Rapids of the Drowned, CL = Cunningham Landing, SR = Salt River, and SRD = Slave River Delta.
2. Dog = dog food and Human = human consumption.

5.1.3 Northern Ecosystem Protection

a) Aquatic Biota and Habitat

Aquatic organisms have very specific requirements, in terms of the physical, chemical, and biological characteristics of water, which must be met to maintain the health and vitality of their populations. Changes in the physical (ie. temperature, streambed substrate composition, etc.) and/or biological (ie. distribution and abundance of important fish food organisms) characteristics of a stream system may have serious effects on the populations of important sport fish species. Similarly, changes in water chemistry may result in direct uptake of contaminants, in low level sub-lethal effects, or in acute toxicity to sensitive species.

b) Recreation and Aesthetics

Tourism is a major growth industry in the NWT. However, many of the activities associated with tourism (ie. nature excursions) are dependent on the perception that vacation destinations represent pristine wilderness areas; these commodities are in short supply in much of North America. Contamination of water resources in the NWT with industrial, agricultural, and municipal wastes, even at low

levels, has the potential to destroy this perception, and in so doing, severely affect the tourism industry.

Sport fishing is a major recreational activity in the NWT that currently contributes millions of dollars to the regional economy. Even the most conservative predictions suggest that sport fishing is going to increase dramatically in importance throughout North America (ie. the number of people involved in the sport fishery in the United States is predicted to increase by 25% by the year 2000; Sport Fishing Institute, Washington, District of Columbia. Personal communication). It is likely that the fishing effort expended in the NWT will increase at a higher rate than other locations in North America due to its exceptional fisheries resources (ie. there is abundance of desirable sportfish species available, such as walleye, inconnu, and northern pike). Changes in the quality and/or quantity of sportfish species available to the sport fishery have the potential to seriously affect this aspect of the tourism industry.

Northern ecosystem protection has been identified as the highest priority water management goal in the NWT (Letourneau et al. 1988). Realization of this goal necessitates protection of aquatic biota, aquatic habitats, and the water uses that rely on these resources in the NWT. In addition, the perception of the Slave River as a pristine watercourse must be protected and enhanced to realize the full economic benefits of the system within the NWT.

5.2 Objectives of the Slave River Basin Monitoring Program

To be effective, the Slave River monitoring program must provide information required by water managers in the NWT. Participants at the Strategy Session indicated that the environmental quality monitoring program for the Slave River basin should be primarily designed to address concerns over human health associated with the use of the aquatic resources (compliance monitoring). The major uses of aquatic resources in the Slave River basin include water withdrawals for domestic water supplies and fisheries uses for domestic protein supplies. In addition, the monitoring program should be directed at detecting and quantifying changes in environmental quality over time (trend assessment monitoring).

The recommended monitoring program was designed to respond to the distinct requirements of the two major monitoring goals. The integrated multi-media monitoring component of the program, which is scheduled for implementation in 1990, is designed to provide information which may be used to assess compliance with established environmental quality guidelines (Canadian Council of Ministers of the Environment 1987; Health and Welfare Canada 1987) or transboundary environmental quality objectives which may be negotiated in the future. In addition, integrated multi-media sampling will provide information on environmental quality conditions prior to the expansion of developmental activities in upstream locations. As such, the program is designed to generate

data on levels of priority environmental quality variables in three of the major ecosystem compartments: water, suspended sediment, and fish.

The trend assessment component of the program is designed to identify appropriate long-term indicators of environmental quality in the Slave River, and is scheduled for implementation in the near future (after the completion of the reconnaissance program). The establishment of baseline conditions (1990 program) may also contribute to the assessment of trends over the long term. Each of the components of the overall Slave River monitoring program will be addressed separately in the following chapters (7 - 10) of this report.

Chapter 6

The Slave River Integrated Multi-Media Monitoring Program: Quality Assurance/Quality Control

6.0 Introduction

Quality assurance (QA) refers to the total integrated program for assuring reliability of monitoring and measurement data. Quality control (QC) relates to the routine application of procedures for obtaining prescribed standards of performance in the monitoring and measurement process. The overall goal of the QA/QC program is to ensure a high level of confidence in the data that is generated by the monitoring program. A defensible QA/QC program must address potential problems that can develop during field sampling, laboratory analysis, and data processing.

6.1 Field Sampling and Laboratory Procedures

Prevention of contamination of environmental samples must be a foremost consideration in the field sampling program. There are abundant examples of spurious results in water quality databases, and many of these are due to contamination of samples in the field. Perhaps the most common source of contamination in water samples is mercury from broken thermometers or Water Survey of Canada manometers. Contamination of water samples in the field may also occur due to the use of improperly selected or prepared sample containers or contaminated preservatives. Collection or filtration of samples in areas where gas or diesel powered equipment or wood smoke is present may result in contamination, particularly with nitrogen and hydrocarbons.

A fundamental step towards assurance of high quality field sampling is the explicit definition of the monitoring program design and specific sampling protocols. The present report can serve as a model for the final monitoring design document. In addition, sampling should be conducted at fixed sites that are readily identifiable and have been evaluated to determine that representative samples can be consistently collected.

Several procedures are recommended here to help reduce the number and severity of sampling and analytical errors in the various components of the monitoring program.

a. Establish a clear link between the monitoring program design and the field sampling program. The most efficient way to develop this link is to form a study team that includes both program design and field sampling staff. This action will ensure that field sampling personnel are involved in, and provide input to, the

monitoring program at the design phase. Effective communication between the members of the study team is critical to the success of the program.

b. Initial site visits should involve both program design and field sampling personnel. This will ensure that the entire study team have a complete understanding of where and how sampling is to take place.

c. Sampling protocols should be explicitly defined to provide reference material for field staff. These protocols should address issues such as sample volumes, equipment preparation (ie. to prevent cross contamination where equipment is used at multiple sites, etc.), and sample collection, labelling, preservation, and transport procedures. A clear description of the information required in field notes should be provided in the protocol document as well. Errors and omissions in the protocol document (or the absence of a protocol document) virtually guarantee problems with interpretation of the resultant data.

d. Field sampling procedures should be audited periodically by other members of the study team to ensure that sampling protocols are being carried out as specified.

e. Field sampling equipment (such as pH meters, saturometers, DO meters, Hydrolabs, etc.) should be regularly calibrated and adequately maintained.

f. Replicate sampling provides a means of quantifying small-scale variability in environmental quality and identifying obviously spurious results. For this reason, replicate sampling is recommended in the present monitoring program design.

g. Blank water samples should be prepared in the field to help identify systematic errors arising from field sampling, sample preservation, and sample transport and storage procedures. In addition, these blank samples provide an additional check (in addition to method blanks) for errors that might arise from analytical procedures. These blanks should be part of a 'blind' analytical program to ensure that they are treated in the same manner as other samples by analytical personnel.

h. For complex and expensive analyses (such as those that might be run on large volume extraction samples), a proportion of the samples should be split to test the precision of the analytical procedures. In addition, analysis of standard spiked samples that have been prepared by other laboratories should be included in the QA/QC program. Once again, splits and spikes should be part of a 'blind' analytical QA/QC program.

i. The laboratories chosen to analyze samples should have acceptable QA/QC programs in place, and the results of these programs should be regularly evaluated by members of the study team.

6.2 Data Management Procedures

The term data management describes the process whereby environmental quality data are collected, validated, stored, transferred, reduced, and analyzed to provide a product that may be used, with confidence, by water managers and by the public. Quality assurance must be explicitly addressed in each of these aspects of the data management program to ensure the integrity of the final product.

a. The quality assurance plan must address how data are to be collected after sample analyses are complete. Internal checks are required to ensure that data transcription procedures (both manual and electronic) are completed in a timely and error-free manner.

b. Data validation is a critical component of the quality assurance program. Efficient and effective data validation requires definition of a specific set of criteria for accepting or rejecting the data that have been collected. In addition, this aspect of the program should have a well defined protocol of checking analytical results that are rejected at this stage (ie. confirming data with original lab data, re-analyzing samples, etc.)

c. The Slave River monitoring program necessarily requires provisions for long-term data storage. Therefore, procedures must be developed to ensure data integrity and security. The quality assurance plan should indicate how specific types of data will be stored with respect to media, conditions, locations, retention time, and access.

d. Data reduction includes all processes which change either the form of the expression or quantity of data values. This set of procedures includes validation, verification, and statistical and mathematical analyses. The quality assurance plan should describe how data reduction will be conducted and how the accuracy, precision, completeness, representativeness, and comparability of the data will be assessed and expressed.

Some of the components of the quality assurance/quality control plan for the Slave River monitoring program are described in the appropriate sections of this document. These address only the aspects of the QA/QC program that apply to the field sampling portion of the program. A detailed QA/QC manual is currently being

prepared by NWRI staff at the Canada Centre for Inland Waters (Burlington, Ontario). This manual should be obtained and evaluated when it is completed, and appropriate recommendations should be implemented as part of the Slave River monitoring program.

Chapter 7

The Slave River Integrated Multi-Media Monitoring Program: Water

7.0 Introduction

The Slave River is an important source of water for domestic use in the NWT. Therefore, the quality of drinking water supplies must be addressed to allay public concerns related to human health. The water quality monitoring component of the Slave River program is designed to provide information with which to assess compliance with the Guidelines for Canadian Drinking Water Quality (Health and Welfare 1987). In addition, this component of the integrated multi-media monitoring program is designed to provide baseline water quality data prior to the expansion of industrial development in the upstream portions of the basin. As such, these data may be appropriate for assessing gross changes in water quality that could occur in the future.

7.1 Potential Sampling Locations

The Slave River system integrates flows from the Peace River and the Athabasca River downstream of Riviere La Roche. The streamflow of the Slave River is augmented by inputs from several tributary streams between Riviere La Roche and Great Slave Lake, most of which are relatively minor. However, the Salt River has very different water quality characteristics and contributes significant quantities of water to the system. Therefore, long-term monitoring that is focused on detecting shifts in water quality due to inputs from upstream sources ought to be located upstream of the Salt River.

Two of the most logical choices for monitoring stations were considered to be the Slave River at Fitzgerald and the Slave River at Fort Smith. The Fitzgerald site was considered to be attractive because data have already been collected on water quality (1960 - present) and quantity (1916 - present). However, serious difficulties have been experienced at the Fitzgerald site with respect to sampling for fish; this would preclude the co-location of sampling sites for all of the media types. Similar problems are not apparent at the site located at Fort Smith. The Fort Smith site is also attractive because it is located within the territorial portion of the basin, it provides a discrete population of fish in the NWT (due to the barrier that is created by the Rapids of the Drowned) and it is easily accessible from the townsite. In addition, many of the variables and sampling methods identified in the recommended monitoring program have not been included in the program conducted at Fitzgerald, and therefore the comparability of the data is not a

major consideration. Therefore, Fort Smith was selected by Strategy Session participants as the most appropriate site for a long-term monitoring station on the Slave River. It was further decided that the sampling site should be located downstream of the Rapids of the Drowned and upstream of the influence of the sewage discharge. A permanent sampling location should be selected after an on-site reconnaissance survey of this stream reach (approximately 3 km) has been completed.

7.2 Station Evaluation

As indicated above, the exact sampling location at the Fort Smith station will be chosen after an on-site reconnaissance has been conducted. In general, sampling stations should be chosen in stream reaches that are well mixed, with linear flow patterns and typical cross-sectional structures. A location downstream of the Rapids of the Drowned should be well mixed and would, therefore, be expected to be representative of water quality conditions within the stream reach.

Strategy Session participants did not address the need for station evaluation in the water component of the integrated multi-media monitoring program. However, one of the foremost considerations when developing a long-term water quality monitoring program is to determine if representative samples can be obtained routinely from the sites under consideration. Lotic systems are dynamic in nature, and, therefore, water quality varies on both spatial and temporal bases (MacDonald and Valiela 1988). Spatial variability at a monitoring station can exist on several distinct scales. Small scale variability applies to the heterogeneity of water quality characteristics within a small volume of water (ie. 1 cubic meter). Cross-sectional variability applies to the changes in water quality across the width of a river. Vertical variability applies to alterations in water quality with depth. All of these sources of variability may operate simultaneously in stream systems, making definition of acceptable sampling sites difficult. In many cases, water quality monitoring stations have been selected without due consideration of within site and between site variability. Station evaluation is the process whereby specific sampling locations are assessed to determine if they are representative of ambient water quality conditions.

Sources of variability in water quality and sampling strategies that are normally employed to assess variability are itemized in Table 3. In spite of the confidence that Strategy Session participants had in their ability to select a representative sampling site, it is still advisable to conduct a station evaluation to generate confidence in the resultant data. In addition, while large volume sampling methods may be considered to be 'state of the art,' it is not advisable to simply 'jump on board' without calibrating these data against those which are collected using conventional sampling methods. Further, collection of single (albeit composite) samples using the large volume sample methods raises some concern over our

ability to distinguish sample contamination from environmental contamination, particularly for hydrocarbons. Therefore, we strongly recommend that a well defined field quality assurance/quality control program be included as an integral part of the monitoring program in 1990.

Table 3. Sources of variability in water quality data.

Source of Variability	Strategy for Assessment of Variability
Small scale spatial variability (m^3)	Replicate sampling.
Variability with depth	Comparison of depth integrated sampling data with grab sampling data.
Cross-sectional variability	Station evaluation.
Longitudinal variability	Not addressed in study design; monitoring program design focused on upstream sources of contamination.
Short-term temporal variability	Intensive sampling during station evaluation (3 sampling times/day).
Seasonal variability	Intensive sampling during spring freshet (weekly sampling).
Annual variability	Fixed frequency sampling to facilitate statistical analysis.
Natural variability	Incorporation of reference or control stations.

7.3 Priority Water Quality Variables

The water component of the Slave River integrated multi-media monitoring program is designed to address human health and environmental concerns within the territorial portion of the basin. As such, the monitoring design considers both existing concerns and issues that may arise due to projected upstream developmental activities. An assessment of which contaminants are likely to be associated with industrial, agricultural, and other activities in the upstream portion of the basin resulted in the preparation of a list of priority water quality variables (MacDonald 1990).

Strategy Session participants evaluated this list of priority variables to identify the variables which should be included in the water component of the program. Those variables which were considered to be highest priority for inclusion in the monitoring program are discussed below.

7.3.1 General Variables

A number of general variables were recommended for inclusion in the water quality component of the monitoring program. At the Fort Smith site, these variables include BOD, COD, colour, conductivity, dissolved oxygen (DO), fecal coliforms, hardness, odour, pH, radionuclides, streamflow, suspended sediment, taste, and temperature. Although radionuclides are included in the interim GNWT/Alberta transboundary monitoring program, they were deemed to be optional for the present sampling program.

7.3.2 Anions

A standard suite of anions was recommended for monitoring at the Fort Smith site, consisting of chloride, sulphate, and sulphide. There was a suggestion to add chlorate to the regular suite of anions since it is a by-product of the new technology that is currently being adopted at some of the pulp mills in upstream locations.

7.3.3 Pesticides

A diversity of pesticides are currently in use in upstream portions of the river basin. Only a few of these pesticides have been addressed in the DOE monitoring program on the Slave River. Of the limited suite of pesticides addressed, only phenoxy herbicides have been detected in water. For this reason, Strategy Session participants recommended that only phenoxy herbicides should be measured in the first year of the monitoring program. Therefore, the most relevant pesticides for the water component of the monitoring program were thought to be 2,4-D, 2,4,5-T, and MCPA. Pesticide use in upstream locations and the probability of detection in water in the NWT should be evaluated on an annual basis to identify which pesticides should be included in the monitoring program.

7.3.4 Organochlorines

Strategy Session participants recommended that broad scans for chlorophenols and related chlorinated compounds (including guaiacols, catechols, anisoles, and veratroles) be run on water samples from the Fort Smith site. It was also recommended that AOX and EOCL be included in this component of the monitoring program. It was thought that the AOX and EOCl analyses would

provide an index of contamination by chlorinated organic compounds in water. The use of neutron activation was recommended for the EOCL analysis because it is more sensitive than other methods. Dichlorodimethylsulfone was recommended for inclusion in the monitoring program because it is directly related to the odour produced as a result of pulp mill activities and it has been included in the Alberta Environment monitoring program.

7.3.5 Polynuclear Aromatic Hydrocarbons

Strategy session participants indicated that only two polynuclear aromatic hydrocarbons were appropriate for analysis in water. These were benzo(a)pyrene and naphthalene.

7.3.6 Other Organic Compounds

Monoaromatics, such as benzene, toluene, and xylene, were also considered to be priority water quality variables at the Fort Smith site. However, it was considered unlikely that these compounds would be detected in the Slave River as far downstream as Fort Smith due to their high volatilities.

7.3.7 Other Variables

Strategy Session participants decided that nutrients and metals/metalloids should not be included in the water portion of the program.

7.4 Sampling Frequency

Strategy Session participants proposed two different sampling regimes for many of the variables included in the water component of the program. These included monthly sampling and seasonal sampling (4-6 times/year) during key periods of the hydrological cycle. These two sampling regimes are applicable to monitoring for anions and all general variables, with the exceptions of colour and radionuclides. It was suggested that water samples be taken during low flow periods for colour determinations. Monitoring for radionuclides was considered to be an optional component of the program.

Both sampling regimes proposed for general variables and anions should be considered and evaluated by the Slave River Monitoring Technical Sub-Committee. However, preservation of any of the statistical integrity of the monitoring program will require at least monthly sampling at the Fort Smith site for those variables which are strongly dependent on flow (ie. anions and most of the general variables). Adoption of this fixed frequency sampling strategy for general variables and anions will also ensure that the

data generated will be compatible with the data collected by upstream jurisdictions.

Strategy Session participants suggested that sampling for toxic organic substances take place during moderate and low flow periods (September 1 - October 15 and February 1 - March 15, respectively). It was thought that this sampling protocol would maximize the potential for detection of toxic substances by minimizing the dilution effect from runoff. However, it is unlikely that limited sampling will provide a comprehensive evaluation of the nature and extent of contamination in the Slave River system. The potential for false negative results is simply too great.

7.5 Sampling Methods

Strategy Session participants recommended that water quality sampling should be expedited using a submersible pump and a continuous flow centrifuge to separate the water and suspended sediment fractions. The water would then be passed through an extraction unit and chemical analyses would be performed on the sample extracts.

However, this methodology is not appropriate for a number of the variables which were recommended for analysis in water. Specifically, it seems unlikely that representative samples for analysis of coliform levels would be obtained using these techniques (ie. particulate materials are likely to be retained by the centrifuge). Therefore, faecal coliform samples ought to be collected prior to passing the water through the centrifuge. Samples for analysis of BOD, COD, and dissolved oxygen should be collected in a similar manner.

Water samples for inorganic analyses (anions, colour, conductivity, hardness, and pH) should be collected in 1 L plastic bottles and stored at 4°C prior to shipment to the laboratory for analysis. Water samples for analysis of BOD, COD, and dissolved oxygen should be carefully collected in 300 mL glass bottles with ground glass stoppers. The Analytical Methods Manual (Environment Canada 1974) provides acceptable protocols for the collection and analysis of these samples.

It was felt that the high cost of analyses for, and low probability of detection of, complex organic chemicals precludes their inclusion in the rigorous trend assessment component of the monitoring program. However, potential contamination of the water column by these compounds must be addressed. Therefore, it was recommended that water samples should be collected biannually at the Fort Smith station for broad spectrum analyses.

Strategy Session participants suggested that all water quality sampling be undertaken at a fixed point and depth in the cross-section using a method which is consistent with large volume

extraction methodology. Using this technique, water is pumped into a continuous-flow centrifuge to separate the suspended sediment from the water. Water samples for analysis of trace organic contaminants should be collected, after centrifugation, in large glass carboys [20 L or more; washed (Chromerge followed by soap and water), triple-rinsed with double deionized water, heat treated and rinsed with analytical grade hexane]. These carboys should be stored in the dark at 4°C and shipped to the laboratory for extraction. Alternatively, the sediment-free water may be passed through an in situ extraction unit (Neilson and Stevens 1988). Sample extracts should be collected in pre-cleaned 500 mL amber glass bottles and stored in the dark at 4°C for subsequent analysis.

The inclusion of a basic bioassay screen of water extracts used for organic analyses was recommended by the Strategy Session participants. Pre-screening for potentially toxic substances could be used to ascertain the need for more complex chemical analyses. This approach may prove useful for the detection of toxic substances present in the water column which were not specifically analyzed for. The organism(s) used in the bioassay could be chosen with relevance to the Slave River ecosystem or with reference to previously standardized tests. Such procedures could be parallelled with suspended sediment extracts for insight into the partitioning of various contaminants between these two components. Algal screening tests on water samples collected during late winter, low flow periods were also suggested by the participants, to determine the presence or absence of phytotoxic substances. As the nature of contaminants in the water column may change with time, this approach could provide an early-warning system for detection of toxic substances that are not currently being monitored. Such bioassays may offer relevant information on the biological effects of below detection limit concentrations of contaminants in the water extracts, if such contaminants are subsequently identified through chemical analyses.

7.6 Sample Preparation and Archiving

The preservation, storage, and analytical protocols used in large volume sampling should be consistent, and developed in cooperation, with the NWRI (PERD) study. Data so generated will be compatible with data from the NWRI (PERD) study and the Wood Buffalo National Park Monitoring Program. Where multidetector scans indicate the presence of various classes of organic chemicals, more comprehensive analyses may be required to determine their specific identities.

The details of all water collection activities should be documented in a permanent log book. This should include date (day/month/year), starting time, finishing time, volume of water centrifuged, location, depth of collection, and the name of the sampler(s). Water samples should be identified by site, date, time, and sample number.

Archiving of water samples was not recommended by Strategy Session participants for the first year of the program.

7.7 Quality Assurance and Quality Control

Generation of reliable water quality data is an essential component of the Slave River monitoring program. However, to avoid problems associated with data of questionable reliability, it is necessary to implement adequate quality assurance and quality control measures in the monitoring program. The general principles which should be considered in the development of a field, laboratory, and data management QA/QC program are addressed in Chapter 6. More specific recommendations on the field sampling component of the program are provided below.

Procedural blanks provide a valuable means of identifying sources of contamination in the field sampling methodology. With respect to water quality sampling, procedural blanks should be prepared using double deionized (DDI) water. Twenty litre carboys of DDI water should be prepared in the laboratory and shipped to the sampling site. This DDI water should be centrifuged and passed through the large volume extraction unit in a manner consistent with the collection of river water samples. Sample extracts should be labelled, preserved, shipped, and stored with river water extracts prior to analysis to ensure that they are exposed to all potential sources of contamination. Analytical personnel should not be informed about which samples are blanks and which are river water extracts.

Sample splitting provides a means of assessing the reproducibility of the analytical procedure. Split samples should be considered to be an integral part of the QA/QC program, and as such should be prepared consistently throughout the monitoring program.

Sample spiking also provides a means of evaluating the reliability of analytical procedures. Spiked samples should be prepared by certified laboratories and included in the shipment of samples (river water extracts, blanks, and splits) for analysis.

Evaluation of the results of the blank, split, and spiked samples provides a means of evaluating the reliability of the database generated on river water quality. Without these data, it is impossible to determine how much confidence can be placed in the results of the monitoring program.

Chapter 8

The Slave River Integrated Multi-Media Monitoring Program: Suspended Sediment

8.0 Introduction

Particulate matter plays a critical role in the physical movement, chemical speciation and biological fate of a wide variety of environmental contaminants (Allan 1986). While bed sediments are the primary contaminant sink in aquatic ecosystems, suspended sediments play a central role in the downstream transport of organic contaminants (such as those originating from pulpmills and petroleum developments) and metals. Adsorption of hydrophobic substances onto suspended particulate matter also affects the bioavailability of these pollutants and their potential for bioaccumulation in aquatic organisms (Allan 1986). Subsequent desorption of toxic chemicals from suspended or deposited sediments can result in the degradation of the quality of the surrounding water. Therefore, data on levels of contaminants in suspended sediments, in conjunction with data on contaminants in water and biota, will provide water managers with information on baseline environmental quality conditions in the territorial portion of the basin.

8.1 Potential Sampling Locations

As with water quality sampling, there are several sites which may be appropriate for sampling suspended sediment. Of these, the Slave River at Fitzgerald and the Slave River at Fort Smith were considered to be the best candidate sites for monitoring the quality of suspended sediments. The Fort Smith site was selected for monitoring water quality in the Slave River. Since co-location of the water and suspended sediment sampling sites was deemed to be imperative, the Fort Smith site was also chosen for the suspended sediment component of the integrated multi-media monitoring program.

In recent years, environmental monitoring programs have increasingly included sampling of suspended sediment to provide a more comprehensive picture of the distribution of contaminants in aquatic ecosystems. Many toxic chemicals have been found to be closely associated with suspended particulates and bottom sediments (Merriman 1988; Ongley et al. 1988). In these studies, analysis of trace contaminants in water (ie. filtered samples) routinely indicated concentrations below the limit of detection. These results suggest that suspended sediment may be an appropriate medium for monitoring certain organic compounds related to environmental quality.

While suspended sediments may be reasonable indicators of environmental quality, interpretation of these data is difficult. Currently, no environmental quality guidelines exist for contaminants in suspended sediment. The water quality guidelines developed by the Canadian Council of Ministers of the Environment (CCREM 1987), because they apply to unfiltered (total) water samples, may be of some relevance for evaluating the quality of suspended sediments. In addition, the ultimate fate of these suspended sediments is largely unknown and the extent of biotic interaction with these sediments is undefinable.

8.2 Priority Variables for Suspended Sediment Monitoring

Strategy Session participants felt that concurrent sampling of water and suspended sediment was likely to provide relevant data for evaluation of baseline environmental quality conditions in the Slave River. Suspended sediments were considered an appropriate medium for monitoring contaminants that are associated with a wide variety of developmental activities (including LRTAP). The resulting data may provide an indication of the quality of surficial bottom sediments in downstream locations within the river basin. This, in turn, could provide guidance on the implementation of the trend assessment component of the overall program. The variables that were recommended for inclusion in the suspended sediment component of the monitoring program are listed below.

8.2.1 General Variables

The general variables that were recommended for monitoring at the Fort Smith site included particle size distribution (% clay/silt and % sand), suspended sediment concentration, total organic carbon (TOC), and total extractable carbon. It was further recommended that chemical analysis be run, preferentially, on samples that have been split into specific size classes [clay/silt (<0.0625 mm) and sand (>0.0625 mm)].

8.2.2 Metals

The Strategy Session participants suggested that a broad suite of metals should be analyzed (utilizing an ICAP scan) in suspended sediment. This was suggested because participants felt that the bulk of the metals load would be associated with the particulate fraction. Both extractable and total metals and metalloids were suggested for inclusion in the monitoring program.
It should be noted, however, that toxicity has most often been correlated with concentrations of dissolved metals, as this fraction tends to be highly bioavailable. Strategy Session participants did not address the question of bioavailability of metals.

8.2.3 Pesticides

There are two major sources of pesticide contamination in the Slave River basin; agricultural and silvicultural use in upstream areas and long range atmospheric transport. The highest priority pesticides for analysis in suspended sediments were deemed to be toxaphene, triallate and trifluralin. Both triallate and trifluralin are known to be used in upstream areas and transported on suspended sediment. Toxaphene, which is considered to be a LRTAP compound, is also known to form associations with suspended particulate matter. Methoxychlor was also recommended by some participants, however suspension of the use of this compound for black fly control in Alberta reduces its priority for inclusion in the monitoring program. In 1988, this substance was included as part of the fish flesh monitoring program in the NWT and was not detected.

8.2.4 Organochlorines

Strategy Session participants recommended that broad scans for chlorophenols and related chlorinated organic compounds (including guaiacols, catechols, anisoles, and veratroles) be run on suspended sediment extracts from the Fort Smith site. It was also recommended that EOX and EOCL be included in this component of the monitoring program. It was thought that the EOX and EOCl analyses would provide an index of contamination by chlorinated organic compounds in the suspended sediment.

8.2.5 Polychlorinated Biphenyls

It was recommended that total PCBs and specific congeners be analyzed in suspended sediment extracts. The specific congeners that were identified included 28, 52, 99 or 101, 118, 138, 153, 170, and 180. Although the participants thought concentrations of these compounds may not be high enough for detection, it was felt that the data would provide useful information on existing conditions.

8.2.6 Polynuclear Aromatic Hydrocarbons

As PAHs are generally associated with the suspended sediment, the participants suggested that these variables could be included in the monitoring program with the option of removing them at a later date. No specific guidance was provided on which polynuclear aromatic hydrocarbons should be addressed in the program. The results of the upstream PERD study may provide the information required to identify priority variables in the Slave River monitoring program.

8.2.7 Other Organic Compounds

In addition to the variables identified above, Strategy Session participants recommended that an alkane screen be performed on sample extracts. It was thought that these data would be useful for distinguishing anthropogenic sources of hydrocarbons from natural sources.

8.3 Sampling Frequency

Strategy Session participants suggested that sampling activities for suspended sediments should be synchronized with the water quality component of the monitoring program. A sampling regime of once or twice per year for metals, PCBs, and organochlorine compounds was suggested.

8.4 Sampling Methods

Strategy Session participants recommended that suspended sediment samples be obtained using a methodology consistent with that employed in the PERD program. This procedure calls for the use of a submersible pump with teflon-lined stainless steel braided tubing to collect raw water samples. Ideally, these samples would be taken at a representative location on the cross-section at 0.6 times the total water depth. However, it may be difficult to obtain samples from this depth given the substantial water velocities that are evident downstream of the Rapids of the Drowned. The raw water samples are then separated into their component parts (water and sediment) using a portable, continuous-flow centrifuge (Ongley and Blachford 1982).

Approximately 30 to 40 g of suspended sediment will be required to obtain acceptable detection limits for sediment-associated contaminants. It would be prudent to collect an additional 100 to 200 g of sediment to ensure that there is an adequate supply for sample splits and sample archiving. The time required to acquire this amount of sediment will be dependent on the suspended sediment concentration at the time of sampling. The potential benefits of employing two centrifuges would include reduced sampling time, as well as the ability to designate one centrifuge specifically for the contaminant analyses and the other for the determination of physical variables. The stainless steel centrifuge bowls should be rinsed with analytical grade acetone prior to sample collection. Sampling depth must be considered due to the relationship of increasing particle size with increasing depths. Karichkoff et al. (1979) reported differential adsorption of hydrophobic compounds between the silt and clay sized fractions, due to their organic carbon content.

Sediment samples should be placed in wide-mouthed teflon or glass jars (heat treated and rinsed with hexane or acetone). The jars (at least 125 mL capacity) should be sealed with teflon lids or linerless plastic lids with a foil liner (heat treated and hexane or acetone rinsed). Individual suspended sediment samples should be labelled and carefully packed on ice in coolers. If glass jars are used, suitable precautions should be taken to avoid breakage during transport to the laboratory.

The inclusion of a basic bioassay screen of suspended sediment extracts used for organic analyses was recommended by the Strategy Session participants. A pre-screening for potentially toxic substances could be used to ascertain the need for more complex chemical analyses, and may be an early-warning indication that the quality of contaminants in the system is changing. This approach may prove useful for the detection of toxic substances present in the suspended sediment fraction which were not specifically analyzed for. The organism(s) used in the bioassay could be chosen with relevance to the Slave River ecosystem or with reference to previously standardized tests. Algal screening tests could be used to determine the presence or absence of phytotoxic substances in the suspended sediment extracts. Such bioassays may offer relevant information on the biological effects of substances in suspended sediment extracts which are not specifically addressed in the analytical program and/or those that are not present at detectable concentrations.

8.5 Sample Preparation and Archiving

The details of all sediment collection activities should be documented in a permanent log book. This should include date (day/month/year), starting time, finishing time, volume of water centrifuged, weight of suspended sediment collected, location, depth of collection, and the name of the sampler(s). Sediment samples should be identified by site, date, time, and sample number.

Sediment samples should be stored in the dark at 4°C or frozen prior to shipment to the laboratory for analysis. Sediment samples should be sieved in the laboratory, using appropriate methods, to split them into the two size fractions (clay/silt and sand) prior to chemical analysis. Archive samples should be clearly labelled and stored at -80°C.

8.6 Quality Assurance and Quality Control

Generation of reliable data on the quality of suspended sediments is an essential component of the Slave River monitoring program. However, to avoid problems associated with data of questionable reliability, it is necessary to implement adequate quality assurance and quality control measures in the monitoring program. The general principles which should be considered in the development of a field, laboratory, and data management QA/QC program are addressed in Chapter 6. More specific recommendations on the field sampling component of the program are provided below.

No acceptable methods have been developed for evaluating sources of contamination in the field sampling methodology for suspended sediments. There may, however, be a potential to utilize reference sediments in this aspect of the QA/QC program.

Sample splitting provides a means of assessing the reproducibility of the analytical procedure. Split samples should be considered to be an integral part of the QA/QC program, and as such should be prepared consistently throughout the monitoring program.

Sample spiking also provides a means of evaluating the reliability of analytical procedures. Spiked samples should be prepared by certified laboratories and included in the shipment of samples (river water extracts, blanks, and splits) for analysis.

Evaluation of the results of the split and spiked samples provides a means of evaluating the reliability of the database generated on the quality of suspended sediments. Without these data, it is impossible to determine how much confidence can be placed in the results of the monitoring program.

Chapter 9

The Slave River Integrated Multi-Media Monitoring Program: Biota

9.0 Introduction

Monitoring of contaminants in fish in Canada and around the world has indicated that fish tend to accumulate environmental pollutants in their tissues (Wren et al. 1983; British Columbia Ministry of Environment 1979; Swackhamer and Hites 1988; Bowlby et al. 1988, to name only a few). In general, the level of bioaccumulation is dependent on the fate and persistence of the chemical under consideration, the concentrations of contaminants in the environment, and the period of exposure to those concentrations (via water, sediment, and/or biota). While numerous problems exist with respect to using fish as indicators of environmental contamination (ie. for trend assessment), there is no substitute for monitoring of fish flesh quality with respect to assessing risks to human health. As long as fish are consumed by humans, the quality of their edible tissues will have to be addressed by environmental managers on a routine basis.

In Canada, guidelines for contaminant residues in the edible tissues of aquatic biota are developed by Health and Welfare Canada. These guidelines are developed using information available on tolerable daily intakes of contaminants (ie. maximum daily intake rates in mg/kg/day times an appropriate safety factor), in conjunction with data on probable daily or weekly intakes of aquatic biota, on the body weight of the consumer, and on the percentage of the total exposure to the chemical attributable to ingestion of contaminated organisms. Guidelines so developed are designed to protect humans from adverse effects associated with the intake of contaminants that may accumulate in the tissues of aquatic biota. As such, these guidelines are highly relevant and may be easily adjusted to account for differences in body weights or intake rates evident throughout the population.

Currently, guidelines applicable to chemical contaminants in fish in Canada have been established only for polychlorinated biphenyls (2 mg/kg), mercury (0.5 mg/kg), pesticides (ie. 5.0 mg/kg for DDT), and 2,3,7,8 tetrachloro-dibenzo-p-dioxin (20 ng/kg). Information on toxic equivalent factors provides a means of developing guidelines for other dioxins and furans from the 2,3,7,8 TCDD guideline (D.C. Kirkpatrick, Director, Bureau of Chemical Safety, Health Protection Branch, Ottawa, Canada. Personal communication). In addition to these guidelines, the United States Environmental Protection Agency (1987) has developed a number of guidelines for levels of contaminants in edible tissues applicable to human health. Further, Newell et al. (1987) have developed fish flesh guidelines (termed

criteria by the authors) applicable to the protection of piscivorous wildlife.

Upstream developments have the potential to contribute a broad spectrum of environmental contaminants to the Slave River basin. These substances could act additively, synergistically, or antagonistically. Therefore, Strategy Session participants recommended that a variety of additional variables be addressed as part of the baseline assessment component of the program.

9.1 Potential Monitoring Species and Locations

There are a number of factors that should be considered before designing the compliance monitoring component of the program. The first factor that should be considered is which species are consumed in the greatest quantities by local area residents and resident piscivorous wildlife species. In addition, residency time, spawning timing, age at maturity, food sources, sediment exposure, availability, fecundity, and growth rates should all be considered before selecting one or more target species.

Table 4 presents a ranking system for fish species in the Slave River with respect to their suitability as sentinel species. This ranking system assigns points for attributes that contribute to the species utility in a biomonitoring program. In Tables 4 and 5, the term 'use' applies to the extent to which each species is used, and is measured according to percent of catch in the domestic fishery (RL&L and EMA 1985). Residency timing and degree of sediment exposure determines the extent to which fish are exposed to environmental contamination. Spawning timing is important because spawning represents a substantial stress to fish, and necessitates mobilization of lipids. As lipids are the sites of storage for many organic contaminants, changes in lipid content also affect concentrations of contaminants in tissues. Age at maturity and fecundity are considered because these factors affect adaptability of fish species. The food items selected by fish greatly affect the potential for interaction with environmental contamination. The abundance of various fish species greatly affects their utility for biomonitoring because abundant species would be easier and cheaper to monitor. Growth rate is important because it may be related to both contaminant uptake rates and depuration rates. The scoring system used to assess the suitability of the various fish species for biomonitoring is presented in Table 5.

Table 4. Assessment of the suitability of fish species in the Slave River for inclusion in a biomonitoring program[1].

Species	Attributes[2]									Score
	Use	RT	ST	AM	FS	SE	AB	FE	GR	
Lake Whitefish[3]	5+5	2	0	2	1	1	2	0	1	19
Ciscoes	0	2	0	1	0	0	1	0	0	4
Inconnu	5	2	0	2	2	0	1	1	1	14
Goldeye	3	2	1	2	2	0	1	1	1	12
Northern pike	1+5	3	1	2	2	0	1	1	1	16
Burbot[3]	5+5	2	0	2	2	1	1	1	1	20
Walleye[3]	1+5	2	1	2	2	0	1	1	1	16
Suckers (long-nose & white)	3	3	1	2	1	2	2	1	1	16

1. Adapted from Louisiana Pacific, 1988.

2. Use = % catch in domestic fishery
   RT = Residency time
   ST = Spawning timing
   AM = Age at maturity
   FS = Food source
   SE = Sediment exposure
   AB = Abundance
   FE = Fecundity
   GR = Growth rate

3. Lake whitefish, walleye and burbot are used preferentially for human consumption, therefore, 5 points were added to the use score.

The results of this assessment indicate that burbot, walleye, lake whitefish, inconnu, and suckers (longnose and white) are the best candidate species for the compliance monitoring component of the program. Of these, walleye (pickerel), lake whitefish, and burbot should play a central role in the biota component of the integrated multi-media monitoring program (ie. compliance monitoring) because these are the species that are used extensively as food sources by humans. Further, the livers and eggs of burbot are consumed preferentially by native populations. Therefore, these tissues should be explicitly addressed in the compliance biomonitoring program.

Table 5. Summary of information used to score attributes of fish species in the Slave River basin.

Attribute	Scoring Strategy
Use[1]	0 = 0-2% 3 = >5-10% 2 = >2-5% 5 = >10%
Residency Time (RT)	1 = 0-2 months 3 = >4-6 months 2 = >2-4 months 4 = >6 months
Spawning Timing (ST)	0 = summer, fall or winter 1 = spring
Age at Maturity (AM)	0 = 0-3 or >6 years 2 = >3-6 years
Food Source (FS)	0 = plankton and terrestrial insects 1 = benthos and detritus 2 = fish
Sediment Exposure(SE)	0 = infrequent 1 = prolonged.
Abundance (AB)	0 = rare 2 = plentiful 1 = common
Fecundity (FE)	0 = <10,000 1 = >10,000
Growth Rate (GR)	0 = <50% increase in body weight/year 1 = >50% increase in body weight/year

1. Use of fish species was scored in accordance with percentage makeup in domestic catch.

Strategy Session participants recommended that sampling locations coincide with the locations of maximum domestic fishing effort. In the territorial portion of the Slave River basin, these include Fort Smith, Cunningham Landing, and to a lesser extent, the Slave River Delta. Of these, Fort Smith is the most appropriate site, both in terms of importance of the domestic fishery and in terms of the logistics of sampling.

9.2 Priority Variables for Biological Monitoring

Monitoring for compliance necessarily requires environmental quality guidelines and/or objectives against which the resultant monitoring data can be compared. Therefore, Strategy Session participants felt that chemical analyses in this component of the overall program should be limited to the subset of the priority variables for which guidelines are currently available or are likely to be developed in the foreseeable future. Relevant variables for inclusion in this component of the monitoring program are described below.

Although existing Health and Welfare guidelines are essential for providing a framework for compliance purposes, other variables were included in the monitoring scheme to establish a set of baseline conditions prior to the expansion of developmental activities in the river basin. These variables include those contaminants that would be expected to occur in effluents from pulp and paper and hydrocarbon developments. In addition, substances known to contaminate water resources via long range transport (LRTAP) should also be included in the program.

9.2.1 General Variables

Strategy Session participants identified a number of general variables which should be measured in fish. These included length, weight (including the weights of individual organs), age, sex, state of maturity, lipid content and moisture content. Data on these variables are required to provide the basic information for interpretation of the data on chemical concentrations in tissues. In addition, these data may be used to calculate other biological parameters, such as condition coefficient, which may provide some insights into the significance of the chemical data. Important fish health characteristics (biological and pathological descriptions) should be synchronized with this portion of the monitoring program. This information could prove to be relevant in assessing the health of the aquatic ecosystem.

9.2.2 Metals

Guidelines are currently available for only two metals, lead and mercury, in edible fish tissues. Therefore, compliance monitoring can only address these two metals. A major concern with respect to metals is their potential for accumulation in fatty tissues, such as the liver and gonads. In addition, it was recommended that a complete metals scan (ICAP) should be conducted in the first year of the program.

9.2.3 Pesticides

The Strategy Session participants recommended a broad organochlorine scan to address concerns over contamination of fish tissues with

insecticides. However, guidelines for pesticide residues in edible tissues are available for only a sub-set of the organochlorine pesticides used in Canada, namely aldrin/dieldrin, DDT, lindane, mirex, and toxaphene. Two herbicides were identified as having a high potential for bioaccumulation in fish, specifically triallate and trifluralin. Although tissue residue guidelines do not exist for these compounds they were still included in the baseline assessment component of the monitoring program.

9.2.4 Organochlorines

Even though no tissue residue guidelines are available for this class of compounds, a full scan for organochlorine compounds was suggested by the Strategy Session participants to provide data on background levels of various classes of organic compounds. Variables relevant to the compliance monitoring component of the program include 2,3,7,8-tetrachloro-dibenzo-p-dioxin (2,3,7,8-T4CDD) and pentachlorophenol. The scan could identify the need for more specific analyses to support the baseline assessment component of the overall monitoring program.

9.2.5 Polychlorinated Biphenyls

A single guideline currently exists for PCBs, and that applies to total PCBs only. Although measurement of total PCBs was considered to be less useful than specific congener analysis, it was suggested that the monitoring program include measurements of both total PCBs and specific congeners. It was noted that specific congeners were analyzed for and reported by other countries in assessments of the quality of fish destined for export. Specific congeners should include 28, 52, 99 or 101, 118, 138, 153, 170, and 180.

9.2.6 Polynuclear Aromatic Hydrocarbons

Although no guideline exists for benzo-a-pyrene, it was recommended that this variable be included in the baseline monitoring program by Strategy Session participants.

9.2.7 Other Organic Compounds

Strategy Session participants recommended that phenolics and light aromatics be addressed in the baseline monitoring component of the overall program.

9.3 Sampling Frequency and Timing

Strategy Session participants recommended that individual species should be sampled once per year. Optimum sampling timing for each of these species is immediately prior to outmigration to maximize exposure periods. Lake whitefish, and walleye should, therefore, be sampled in the early spring (March -May). Burbot should be sampled during the winter period (December -January). Collection of fish samples during these periods will effectively maximize exposures to environmental contamination.

Another important consideration for determining when to sample is the timing of the domestic fisheries in the Slave River. Human health concerns would be addressed most directly if sampling occurred at the same time that residents fish for their domestic supplies. Strategy Session participants recommended that late summer to early fall was the most appropriate sampling time. It was also noted that weather conditions will influence when sampling can occur for certain species. The spring season is frequently characterized by at least a 3 foot ice cover on the river. In addition, extreme temperatures and strong winds can make sampling for fish during this period very challenging. In 1990, weather conditions severely limited the catches of burbot in the vicinity of Fort Smith.

9.4 Sampling Methods

A variety of sampling methods are available for collecting fish in large river systems. Of these, gill netting, beach seining, electroshocking, and angling tend to be the most effective (in terms of catch per unit effort). In the vicinity of Fort Smith, it is likely that each of these methods would be appropriate for use in certain locations. Overall, Strategy Session participants felt that it would be most effective to use netting techniques during open water periods and to employ set lines (using baited hooks) under ice (ie. for burbot). It should also be noted that a number of effective methods have been developed for deploying gill nets under ice cover. It may be appropriate to experiment with some of these methods in the Slave River during periods of mild weather or with the use of a fishing hut.

Strategy session participants also suggested that the possibility of purchasing locally caught fish should be investigated and pursued if possible. This would ensure that species and sizes of fish collected for the monitoring program are consistent with those collected in the domestic fishery. This is the most direct way to address human health concerns associated with the consumption of fish.

Participants suggested that it would be desirable to collect 20 to 25 individuals of each sex and in each size class for each species that is represented in the domestic fishery. For the first year of the program, it was recommended that a wide range of size classes be sampled, with emphasis on the larger size group that are targeted by the domestic and subsistence fisheries. This would provide an adequate amount of tissue for both immediate analysis and sample archiving. Since as much as 40 g of fish tissue may be required to achieve the desired detection limits for contaminant levels, it may be necessary to composite tissue from several fish to ensure enough liver tissue. It was also recommended that analyses be performed on the tissues of individual fish to provide information on the variability of contaminant levels. However, it may be preferable to pool tissues from 7 to 10 fish and run analyses on the composite sample. When detectable levels of contaminants are measured in the composite samples, samples from each of the fish used to make the composite sample could be analyzed. This procedure is cost-effective and defensible, because it simulates an average exposure that consumers would get from eating several meals of fish.

9.5 Sample Preparation and Archiving

Upon collection, fish should be sorted by species and size class, and individual fish should be measured (length and weight). After sorting and data collection, the fish should be placed in a stainless steel containers for transport. Whole fish should either be double wrapped in treated foil (heat treated and hexane or acetone rinsed) or dissected in the field and placed in glass jars (heat treated and hexane or acetone rinsed) with a Teflon lid. A linerless plastic lid may be substituted for the Teflon lid if a foil liner (heat treated and hexane or acetone rinsed) is used. Each fish should be individually labelled, secured with tape, and placed in a leak proof plastic bag. Samples should be quick frozen on dry ice in the field (when available and appropriate) or placed in coolers on ice.

The details of all fish sampling activities should be documented in a permanent log book. This should include date (day/month/year), time, location, depth of collection, collection method, name of the sampler(s), species, and number of fish collected. In addition, the field sample number (ie. BU90 - 1; for the first burbot collected in 1990), and the length and weight of the specimen should be recorded. These data should also be included with the actual sample. A map of the area, showing the exact location of sample collection, should also be prepared.

Fish samples may be shipped whole to analytical laboratories or dissected prior to shipment. The second option is favoured because it minimizes the potential for confusion on which tissues from individual fish are to be analyzed. Strategy Session participants recommended that fish tissues (separated into flesh and various

organs) be preserved at -80 C for archiving purposes (stable for 10-12 years).

9.6 Quality Assurance and Quality Control

Generation of reliable data on the quality of fish tissues is an essential component the Slave River monitoring program. However, to effectively avoid problems associated with data of questionable reliability it is necessary to implement adequate quality assurance and quality control measures in the monitoring program. The general principles which should be considered in the development of a field, laboratory, and data management QA/QC program are addressed in Chapter 6. More specific recommendations on the field sampling component of the program are provided below.

No acceptable methods have been developed for evaluating sources of contamination in the field sampling methodology for fish tissues. Therefore, extreme care must be taken during the collection and preparation of biological samples to avoid contamination.

Sample splitting provides a means of assessing the reproducibility of the analytical procedure. Split samples should be considered to be an integral part of the QA/QC program, and as such should be prepared consistently throughout the monitoring program.

Evaluation of the results of the split samples provides a means of evaluating the reliability of the database generated on the quality of suspended sediments. Without these data, it is impossible to determine how much confidence can be placed in the results of the monitoring program.

Chapter 10

The Slave River Trend Assessment Monitoring Program: Identification of Indicators of Ecosystem Health

10.0 Introduction

Both contaminated water and contaminated sediment have been identified as potential environmental hazards in the Slave River basin. In addition to the potential for direct toxicological effects, environmental pollutants from anthropogenic sources have the potential to accumulate in bed sediments and the tissues of aquatic biota. Contaminants in bed sediments can provide a long-term route of exposure to aquatic biota, and may, thereby, result in direct toxicological effects and/or bioaccumulation in these organisms. Bioaccumulation in aquatic biota may have significant implications to the species affected and to the aquatic and terrestrial species that rely on aquatic biota to fulfil a portion of their metabolic energy requirements. However, data on levels of contaminants in bed sediments and aquatic biota, when collected in conjunction with other supporting information [ie. species distribution, mixed function oxidase (MFO) activity, etc.], can provide water managers with sensitive indications of the health of the aquatic ecosystem.

The ultimate authorities on the quality of water are the organisms that are exposed to it, not the lawyers, engineers, and environmental scientists who litigate and study it. Data obtained from studying these living models, if properly generated and interpreted, provide empirical evidence with which to assess the quality of the aquatic environment. Further, these data on biotic responses can be correlated with other environmental variables, such as habitat, flow, water and sediment chemistry, and pollution discharges, to increase our understanding of the fate and effects of environmental contaminants. Therefore, the results of integrated bed sediment and biological monitoring programs provide detailed data on the status and health of the biological communities in aquatic ecosystems, and thereby, provide information that is directly applicable to the water management decision making processes.

Integrated bed sediment and biological monitoring in the Slave River basin should be explicitly focused on the assessment of trends in environmental quality. The monitoring program to assess compliance with water quality guidelines is focused on the determination of the quality of fish flesh that may be consumed by humans. In addition, information generated in compliance monitoring component of the program provides an early warning system with respect to degradation of fish flesh quality. The trend assessment component of the monitoring program should be designed to detect subtle shifts in environmental quality. Both

compliance monitoring and trend assessment monitoring need to be adequately addressed in the Slave River basin monitoring program to ensure that instream water uses and consumptive uses of aquatic biota are adequately protected in the NWT.

Monitoring for assessment of environmental impacts was not a prime consideration for inclusion in the first phase of the Slave River basin integrated bed sediment and biological monitoring program. Impact assessment requires a very specialized monitoring design to detect effects on instream biota. In general, benthic community composition (presence/absence data, diversity indices, etc.), growth rates and fecundities of fish, populations of fish and invertebrates, and other similar measures have been used as indicators of environmental impacts. However, without comprehensive ancillary information (co-occurrence of contaminants in sediment and biota), these types of data are extremely difficult to interpret. Further, natural systems tend to be dynamic and cyclical in nature, and therefore anthropogenic impacts are difficult to distinguish from natural variation. The territorial portion of the Slave River is removed from the sites of contaminant inputs. A logical approach therefore would be to incorporate impact assessment monitoring if environmental impacts are demonstrated in upstream locations.

Strategy Session participants provided a plethora of advice on the design of the trend assessment component of the Slave River monitoring program. Unfortunately, the extensive discussions did not resolve the question about which organisms were likely to be appropriate indicators of ecosystem health. Some participants felt that the three species of fish selected to address human health concerns would also be sensitive indicators of the health of the aquatic ecosystem. Other participants felt that benthic macroinvertebrates or aquatic plants would be more appropriate due to their longer residence times and, hence, longer exposure to water and sediment borne contaminants. After a protracted discussion on the topic, it was finally decided that the Slave River Monitoring Technical Sub-Committee would need to make the final selection of appropriate indicator organisms for the trend assessment component of the monitoring program.

The following discussion is provided to assist the Sub-Committee in making its decision on an appropriate biological indicator of trends in environmental quality and ecosystem health

10.1 Monitoring for Trend Assessment

Trend assessment programs require two sources of information in addition to the long-term monitoring data. These include data from a reference station [collected at the same frequency as that of the primary monitoring station(s)] and information on developmental activities in upstream areas. These ancillary data provide the

information required to interpret trends in water quality observed at the primary monitoring station.

While information on levels of contaminants in fish tissues is important for addressing human health concerns, these data do not necessarily provide the information required to assess trends in environmental quality. Many fish species in the Slave River basin are migratory, and have residency times of 6 months or less. For many species, life history strategies have not been well established and therefore interpretation of body burden data is difficult. In addition, many fish species are not available at preferred sampling locations or times, thereby complicating the biomonitoring program.

10.2 Potential Monitoring Compartments for Biotrend Assessment

Bed sediments, aquatic plants, and benthic invertebrates have proven to be sensitive and important indicators of trends in environmental quality due to selective partitioning of toxic contaminants. In addition, these ecosystem components integrate the effects of exposures to contaminants over extended, definable periods of time. Further, many of the biological organisms have been demonstrated to be effective accumulators of many of the priority variables identified in the present study.

A critical component of the recommended integrated monitoring strategy is the simultaneous sampling of streambed sediments and benthic biota to assess the co-occurrence of contaminants in these environmental compartments. Bed sediment sampling is important because many contaminants, particularly non-polar chemicals, are known to associate strongly with suspended and deposited sediments. For these contaminants, downstream transport occurs primarily in association with suspended sediments. Subsequent deposition of these contaminated sediments provides a continuous exposure route to benthic organisms. Therefore, information on both sediment and biota quality is required to assess fully the health of the aquatic ecosystem in the NWT.

10.2.1 Bed Sediments

In recent years, significant sampling and analytical effort has been directed at determining the concentrations and distributions of environmental contaminants in freshwater sediments. The results of a multitude of studies have indicated that many contaminants are preferentially bound to sediments in both lentic and lotic systems. Specifically, metals (British Columbia Ministry of Environment 1979; Wren et al. 1983; Wren and MacCrimmon 1986), pesticides and PCBs (Swackhamer and Hites 1988), fatty acids and resin acids (R. Crozier, BC Ministry of the Environment, Nelson, British Columbia. Personal communication; Rodier and Khalil 1982; Kawamura et al.

1980), hydrocarbons (Meyers and Takeuchi 1979), chlorophenols and related compounds (Baker et al. 1980; Eder 1980; Butte et al. 1985; Remberger et al. 1986), and dioxins and furans (Mah et al. 1989; Czuczwa et al. 1984; Marcheterre et al. 1985) have been measured at elevated levels in bed sediments located downstream of various human developments. Due to their central role in the determination of the fate of a wide variety of compounds and the potential for biotic exposure to contaminated sediments, monitoring of sediments is an important element of the recommended trend assessment monitoring program. As indicated above, this program requires information on the co-occurrence of contaminants in bed sediments and biota, and as such requires a simultaneous sampling protocol.

10.2.2 Algae

Periphyton grown on artificial substrates has been widely used as a tool for biological monitoring of water quality conditions (Leland and Carter 1985; Newman et al. 1985). In addition, algae collected from natural substrates may be used similarly to assess ambient water quality conditions. The major advantages of using periphyton as biomonitoring organisms include: a) they occur in fixed habitats, and so can not avoid pollution episodes; b) they rapidly recolonize substrates after perturbations in water quality or water flow, and therefore are generally available for monitoring; and, c) they are relatively simple to process for analysis. In addition, because different taxa have different tolerances to pollution, species composition and abundance data provide important ancillary information on ambient water quality (Biggs 1985; Biggs 1989).

Algae have been demonstrated to be excellent indicators of metals contamination in a variety of situations, including estuarine (zinc; Cullinane et al. 1987) and riverine systems (cadmium, copper, lead and zinc; British Columbia Ministry of Environment 1979). Further, these ecosystem components have also been proven to be good indicators of pollution by organic compounds, including PCBs (van der Oost et al. 1988; Oliver and Niimi 1988) and pesticides (DDE and HCB; Paasivirta et al. 1983).

10.2.3 Aquatic Mosses

Aquatic mosses have been used in various jurisdictions to monitor pollution by metals (Say et al. 1981, and Whitton et al. 1982) and chlorinated organics. The major advantages of using aquatic mosses as biomonitoring organisms include; a) high tolerances to environmental contaminants, b) long exposure periods are possible due to their perennial nature, c) absence of an active excretion system, d) relatively high lipid contents (1.5 - 4.0 %; Fisque et al. 1983), e) high surface area to volume ratios, and f) differential accumulation rates associated with various age groups, sexes, and body parts are non-existent (Kistritz 1988). Mosses are sessile and may be used to integrate contaminant exposures over

long periods (by in situ sampling) or over short periods (by using the moss bag technique; Mouvet 1985, Wehr et al. 1983). Short-term exposures of aquatic mosses to pesticides (a-HCH, b-HCH) and PCBs resulted in bioconcentration factors in the order of 500 and 5000, respectively (Mouvet 1985).

10.2.4 Rooted Aquatic Plants

Rooted aquatic plants have been used in biological monitoring programs in a manner similar to that of aquatic mosses and periphyton. The major advantage of rooted aquatic plants is that they occur in areas with soft substrates (algae and aquatic mosses occur on hard substrates), and as such integrate the effects of exposures to contaminated water and/or contaminated sediments. Rooted aquatic plants are such efficient accumulators of metals that they have been used in wastewater treatment systems in the vicinity of mining operations (R.U. Kistritz, Kistritz Consultants Ltd., Vancouver, B.C. Personal Communication). In addition, mesocosm experiments in which pond ecosystems were spiked with tetrachlorodibenzo-p-dioxin suggest that rooted aquatic plants take up and retain significant quantities of organochlorine contaminants (Corbet et al. 1983).

10.2.5 Benthic Invertebrates

Benthic invertebrates are ideally suited for biomonitoring because they are non-mobile and tend to be representative of the area being sampled. Populations of many benthic species tend to be relatively stable and therefore require less frequent sampling (Reynoldson 1985). Further, benthic invertebrates are relatively easy to locate and sample. Other advantages of using benthic invertebrates as biological indicators of environmental contamination are associated with their central role as fish food organisms, their demonstrated ability to accumulate metals and organic constituents, and, in many cases, their extended life histories. In addition, the recent development of rapid assessment techniques and batch approaches to bioaccumulation studies may simplify the procedures for dealing with large numbers of benthic macroinvertebrates. The major drawbacks associated with sampling these ecosystem components are associated with difficulties in identification to the species level of organization and with the amount of time required to process samples. Monitoring programs that focus on a single species must also address spatial heterogeneities in benthic populations. Many of these problems are eliminated by considering higher levels of organization (ie. oligochaetes) rather than specific levels of classification (ie. species).

Probably the most promising organisms for trend assessment monitoring in the Slave River basin are freshwater mollusks. The major advantages of using bivalve mollusks and gastropods in biomonitoring programs include their; a) wide geographic distribution, b) non-mobile nature, c) relatively long life-span,

d) high resistance to environmental stresses, and e) high accumulation capacities for a large range of chemicals. The use of mollusks as biological indicators of environmental contamination with metals and organic pollutants has increased dramatically in recent years.

Mollusks are particularly valuable ecosystem components because they are sediment resident and feed on particulate matter that moves along the streambed. Residence in streambed habitats results in direct exposures to contaminants in bed sediment. As detritivours, these species process large volumes of particulate matter and water to obtain the food organisms that they ingest. For these reasons, mollusks tend to have high rates of bioaccumulation for many contaminants. These organisms have been used successfully to assess the significance of contamination by, metals (Jensen et al. 1981), PCBs (Tatem 1986), pesticides (Russell and Gobas 1989), and organochlorines (Satsmadjis and Voutsinou-Taliadouri 1983; Butte et al. 1985). The results of a recent study in the Columbia River have demonstrated that freshwater mussels are also efficient accumulators of dibenzo-p-furans (R. Crozier, Waste Management Branch, Nelson, British Columbia. Personal communication.). Monitoring activities in the Fraser River Estuary have also indicated that these species are sensitive indicators of chlorophenols contamination (Swain and Walton 1988).

Of the benthic organisms sampled in the Fraser River Estuary (Swain and Walton 1988), oligochaetes and polychaetes had the highest levels of chlorophenols in their tissues. As these organisms are resident in streambed sediments, they also have high potentials to accumulate other contaminants that partition into sediments. Ernst and Weber (1978) demonstrated that polychaetes were particularly good indicators of chlorophenols contamination in estuarine ecosystems. A single investigation that focused on PCBs in Lake Ontario suggested that oligochaetes were good indicators of contamination by lower chlorinated biphenyls (tri and tetra) but not the higher chlorinated forms (Oliver and Niimi 1988).

Lamprey ammocoetes (juvenile stage) and leeches have also been evaluated as potential monitoring organisms. These species have been demonstrated to be efficient bioaccumulators of chlorophenols (Metcalfe et al. 1984), as evidenced by elevated levels of these chemicals in their flesh (Swain and Walton 1988). Leeches have also been used to assess levels of environmental contamination with DDT and mirex (Kistritz 1988). Relatively less is known about the potentials of nematodes, decapods, amphipods, and aquatic insects (chironomids, trichopterans, plecopterans, odonatids, and ephemeropterans) for use as biomonitoring organisms. For more information on these organisms see Table 6. Of these, chironomids have been used successfully in field applications to assess metals (Lynch et al. 1988), chlorophenols (Swain and Walton 1988) and PAHs (Gerould et al. 1983) contamination. Amphipods were consistently good indicators of contamination with polychlorinated biphenyls (Oliver and Niimi 1988).

Table 6. Potential benthic biomonitoring organisms for the Slave River integrated monitoring program.

Tahonomic Group	Common Name	Habitat Type	Substrate Type	Trophic Status	Sampling Method	Contaminants Metals	Contaminants Organics	Nutrients
PLANTS								
Benthic Algae	Algae	littoral	rock	autotrophic	harvesting	X		X
Aquatic Mosses	Moss	littoral	rock	autotrophic	harvesting	X	X	
Vascular Plants	Plants	littoral	mud,sand	autotrophic	harvesting	X		X
NEMATODES	Nematode	benthic	mud	detritivore	dredge/screen		X	
ANNELIDS								
Oligochaetes	Bloodworm	benthic	mud	detritivore	dredge/screen	X	X	
Leeches	Leech	general	general	parasitic	trap nets		X	
AQUATIC INSECTS								
Ephemeroptera	Mayfly	epibenthic	general	predacious	surber sampler	X	X	
Odonata	Dragonfly	littoral	vegetation	predacious	trap nets		X	
Plecoptera	Stonefly	epibenthic	rock	detritivore	surber sampler	X	X	
Trichoptera	Caddisfly	epibenthic	general	detritivore	surber sampler		X	
Chironomidae	Midge	benthic	mud,sand	detritivore	dredge/screen	X	X	
MOLLUSKS								
Gastropods	Snail	general	general	herbivore	harvesting		X	
Bivalves	Clan	benthic	sand,mud	detritivore	dredge	X	X	
CRUSTACEANS								
Decapods	Crayfish	epibenthic	general	scavenger	traps	X	X	
Amphipods	Shrimp	benthic	sand,mud	detritivore	dredge	X	X	

10.2.6 Fish

Fish have been used extensively as indicators of environmental contamination in aquatic ecosystems. While fish have been used successfully as qualitative indicators of contamination, their complex life histories and behaviours have limited their utility in trend assessments. For example, levels of chlorophenols in starry flounder (Garrett 1980; Hall et al. 1984; Carey et al. 1986; and Birch 1988) have varied widely with no discernable pattern. Differences in body burdens could be related to differences in diet, period of chemical exposure, age, size, lipid content, and a host of other factors. Similar sources of variability are likely to affect levels of environmental contaminants in fish species in the Slave River basin. Therefore, there may be more sensitive and reliable biomonitoring organisms than fish for assessment of trends in environmental quality.

A notable exception to this rule could be the slimy sculpin. The potential advantages of using this species in a biotrend assessment program include its wide distribution and its non-migratory nature. In addition, this species lives in close association with streambed sediments and, therefore, contaminant burdens are likely to reflect exposure from this source as well as from the suspended sediments and water. Further, sensitive indicators (ie. MFO enzyme activities) have been developed to evaluate contaminant stress in fish species. Therefore, these data may be used to evaluate the significance of contaminant residues in fish flesh.

10.3 Criteria for the Selection of Indicator Species

A priori determination of which organisms, or group of organisms, should be selected for assessment of trends in environmental quality and to assess the health of the aquatic ecosystem is difficult without some criteria with which the suitability of individual species may be evaluated. Acknowledging that point, Strategy Session participants developed a set of criteria for evaluating potential biomonitoring organisms. These include:

* Extended residence time - exposure to environmental contaminants is a function of concentration (in water, sediments, and/or diet) and time. An extended residence time in the Slave River allows for the integration of pollution events (which are often sporadic) over time. When little information exists on the temporal variability in concentration of contaminants, it is prudent to select indicator organisms that have long (greater than six months) residence times. Non-migratory species should, therefore, be favoured over migratory species.

* High potential for bioaccumulation - certain aquatic species have a high potential for bioaccumulation of organic contaminants due to a variety of factors. Since bioaccumulation is frequently correlated with lipid content, those species with high lipid levels (at least in some tissues) should be favoured. Filter feeders and bottom feeders also tend to carry higher contaminant burdens, due to interaction with sediment-borne contaminants.

* Sensitivity to contaminants - species selected as long-term indicators of environmental quality should not be acutely sensitive to contaminant stresses. Sensitive species could experience acute or chronic mortality due to exposure to toxic chemicals. These species would, therefore, be eliminated from aquatic habitats before they can be sampled for contaminant burdens. Species selected as dose-dependent indicators of ecosystem health should demonstrate clear responses to contaminant stresses. If adverse effects are not detected in sensitive species, then less sensitive species and the ecosystem as a whole is likely to be protected (assuming that the methodology used to detect effects is appropriate). The availability of methods to evaluate the health of aquatic biota is central to the assessment of ecosystem health.

* Adequate abundance - candidate indicator species should be abundant and available at a range of sites and times. The life history of the species should also be well documented to facilitate evaluation of life cycle factors that affect body burden and/or organism state.

10.4 Reconnaissance Study to Evaluate Potential Indicator Species

Insufficient information currently exists on the Slave River system to comprehensively evaluate the potential of individual taxa for use as indicator species. Therefore, Strategy Session participants recommended that a reconnaissance study be undertaken to provide basic information on the availability and abundance of benthic organisms and resident fish species. These data, in conjunction with information on bioaccumulation of contaminants in these species in other systems, would provide a defensible means of selecting indictor species for inclusion in the trend assessment component of the Slave River monitoring program.

The reconnaissance study also represents an opportunity to collect baseline data on contaminants in aquatic biota and to archive tissues for subsequent analysis. Therefore, it would be prudent to collect, preserve, transport, and store samples collected during the reconnaissance study in a manner consistent with the procedures

outlined for the biological component of the integrated multi-media monitoring program. Bottom sediments should also be collected in the vicinity of biological sampling sites, for analysis if contamination is detected in biological samples.

10.5 Priority Variables for Biological Monitoring for Trend Assessment

Strategy Session participants provided guidance on which variables should be measured in the biological monitoring for trend assessment component of the Slave River monitoring program. These recommendations specifically apply if a fish species is selected as an indicator organism. However, many of the recommendations apply if other species are selected.

It was suggested that many of the following analyses are required to establish baseline characteristics in terms of contaminant burdens in Slave River biota. Other variables were recommended to provide indications of the overall health and well being of the organisms, species, communities and ecosystem as a whole. Strategy Session participants felt that it would be prudent to test for as many of the contaminants (that were associated with upstream activities) as possible (considering limitations on resources) in the early stages of the program. Only periodic testing in the future would be required for variables that were not detected in the initial survey. Positive results should trigger more intensive sampling.

10.5.1 General Variables

The general variables that should be measured in biological samples in the biotrend component of the monitoring program include general characteristics (length, weight, age, organ weights for fish), lipid content, moisture content, MFO enzyme activities (including EROD, AHH, P450), and individual pathologies (including reproduction, immunochemical responses, tumour frequency, histology of ovarian growth, etc.). In addition, it was felt that trends in population dynamics (ie. species diversity, growth/decline of the community, etc.) should be measured.

10.5.2 Nutrients

It was recommended that total nitrogen (linked to protein/bioenergetics) and carbohydrate content (linked to stress at capture) be measured in biological samples.

10.5.3 Metals

It was recommended that biological monitoring for trend assessment include the full suite of metals (ICAP) and mercury.

10.5.4 Insecticides

A routine scan for organochlorine insecticides was recommended by Strategy Session participants. In addition, specific analysis for total pentachlorophenol in biological tissues was suggested.

10.5.5 Herbicides

While a diverse array of herbicides is used in upper basin areas, only triallate and trifluralin were recommended for analysis in biological tissues.

10.5.6 Organochlorines

Extractable organic chlorine (EOCL) was identified as an indicator variable for organochlorine contamination. Positive results for EOCL in biological samples would indicate the need for a full scan for organochlorines and, subsequently, analysis for specific compounds.

10.5.7 Polychlorinated Biphenyls

Strategy Session participants indicated the need for both total PCB and individual congener analyses. Specific PCB congeners that should be addressed include, at minimum, 28, 52, 99 or 101, 118, 138, 153, 170, and 180.

10.5.8 Polynuclear Aromatic Hydrocarbons

Strategy session participants suggested that a full suite of PAH compounds be measured in fish bile, including diterpene resin acids. No specific guidance was provided on PAH analysis in other tissues or species.

10.6 Design of the Trend Assessment Monitoring Program

Strategy Session participants were unable to reach a consensus on the design of the trend assessment component of the Slave River monitoring program. However, they were able to provide some guidance on various aspects of the monitoring program.

There was extensive discussion on the selection of an appropriate control station(s), but no consensus was reached. Evaluation of the advantages and disadvantages of a number of potential control basins resulted in several recommendations. Use of the Hay River basin as a control was thought to be inappropriate due to the extensive oil and gas and agricultural developments in the Alberta portion of the basin. While Alberta Environment uses the Birch River (in the vicinity of Wood Buffalo National Park) as its control basin, this was considered to be an inappropriate control basin for the NWT monitoring program. With respect to contaminants that are known to sorb onto suspended sediments, a suitable control system should be of similar size and have a similar hydrological regime. The Liard River was considered to be the only candidate basin.

It was generally felt that no one control basin could be used in the NWT monitoring program. Strategy Session participants indicated that for the trend assessment component of the program, it might be possible to sample the same species from a system outside the influence of upstream activities on the Slave River. The monitoring program dealing with mercury in fish has already employed this strategy. It was further indicated that more information on contamination from LRTAP sources was needed to resolve the issue.

MacDonald (1990) provided a detailed design of an integrated bed sediment and biological monitoring program for the Slave River. This program could be used to guide sampling activities during the reconnaissance study.

11.0 References

Alberta Environment. 1989. Surface water quality monitoring in the Peace and Athabasca River basins. Environmental Quality Monitoring Branch. Edmonton, Alberta. 15 pp.

Allan, R.J. 1986. The role of particulate matter in the fate of contaminants in aquatic ecosystems. Scientific Series Number 142. National Water Research Institute. Environment Canada. Burlington, Ontario. 128 pp.

Baker, M.D., C.I. Mayfield, and W.E. Inniss. 1980. Degradation of chlorophenols in soil, sediment, and water at low temperature. Water Research 14:1765-1771.

Biggs, B.J.F. 1985. The use of periphyton in the monitoring of water quality. In: Pridmore, R.D. and A.B. Cooper. (Eds.). Biological monitoring in freshwaters: Proceedings of a seminar. Ministry of Works and Development, Wellington. Water and Soil Miscellaneous Publication 82:117-142

Biggs, B.J.F. 1989. Biomonitoring of organic pollution using periphyton, South Branch, Canterbury, New Zealand. New Zealand Journal of Marine and Freshwater Research 23:263-274.

Birch, G.J. 1988. An investigation of variability of chlorophenols in starry flounder (Platichthys stellatus) from the lower Fraser River. Report prepared by Aquatic Resources Limited for Inland Waters and Lands, Environment Canada.

British Columbia Ministry of Environment. 1979. Kootenay air and water quality study: Phase II. Water quality in the lower Columbia River basin. Water Investigations Branch. Victoria, British Columbia. 238 pp.

Bowlby, J.N., J.M. Gunn, and V.A. Liimatainen. 1988. Metals in stocked lake trout (Salvelinus namaycush) in lakes near Sudbury, Canada. Water, Air, and Soil Pollution 39:217-230.

Butcher, G.A. 1987. Peace River Area, Peace River mainstem water quality assessment and objectives: Technical appendix. Water Management Branch. Ministry of Environment and Parks. Victoria, British Columbia. 226 pp.

Butte, W., J. Denker, M. Kirsch and T. Hopner. 1985. Pentachlorophenol and tetrachlorophenols in Wadden sediment and clams (Mya arenaria) of the Jadebusen after a 14-year period of wastewater discharge containing pentachlorophenol. Environmental Pollution (Series B) 9:29-39.

Canadian Council of Resource and Environment Ministers. 1987. Canadian water quality guidelines. Task Force on Water Quality Guidelines. Ottawa, Canada.

Carey, J.H., M.E. Fox, and J.H. Hart. 1986. The distribution of chlorinated phenols in the north arm of the Fraser River Estuary. Contribution Number 86-45. National Water Research Institute. Environment Canada. Burlington, Ontario.

Corbet, R.L., D.C.G. Muir, and G.R.B. Webster. 1983. Fate of 1,3,6,8-T_4CDD in an outdoor aquatic system. Chemosphere 12(4/5): 523-527.

Crowther, R.A., N.J. Olyslager, J.E. Green and R.R. Wallace. 1990. Examination for the presence of contaminants in the Athabaska River Delta: an analysis of sediments from perched lake basins. Report prepared by Delta Env. Mgnmt. Group for the Athabaska Chipewyan Band, Fort Chipewyan, Alberta.

Cullinane, J.P, T.M. Doyle and P.M. Whelan. 1987. Uses of seaweeds as biomonitors of zinc levels in Cork Harbour, Ireland. Hydrobiologia 151:285-290.

Czuczwa, J.M., B.D. McVeety, and R.A. Hites. 1984. Polychlorinated Dibenzo-p-dioxins and dibenzofurans in sediments from Siskiwit Lake, Isle Royale. Science 226:568-569.

Dominion Ecological Consulting Ltd. and RMC Resources Management Consultants Ltd. 1989. Slave River water quality monitoring workshop: Findings and conclusions. Prepared for Government of the Northwest Territories, Environment Canada, and Indian and Northern Affairs Canada. Yellowknife, Northwest Territories. 31 pp + appendices.

Eder, G. 1980. Formation of chlorophenols from the corresponding chlorophenoxyacetic acids in estuarine sediment under anaerobic conditions. Veroff. Inst. Meeresforsch. Bremerh. 18:217-221.

Environmental Protection Agency. 1987. Quality criteria for water. Criteria and Standards Division. Office of Water. Washington, District of Columbia.

Environment Canada. 1974. Analytical methods manual. Water Quality Branch. Ottawa, Canada.

Ernst, W. and K. Weber. 1978. Chlorinated phenols in selected estuarine bottom fauna. Chemosphere 11:867-872.

Fisque, G.E., M. Galoux, and A. Bernes. 1983. Accumulation de deux micropollutants (les polychlorobiphenyles et le gamma-HCH) par des bryophytes aquatiques de la Meuse. Meded. Fac. Landbouwet. Fijksuniv. Gent. 48:971-983.

Garrett, C.L. 1980. Toxic organic contaminants in sediments and fish from the Fraser River Estuary. Joint publication of the Government of Canada (Environment Canada) and the Province of British Columbia (Ministry of Environment). Vancouver, British Columbia.

Gerould, S., P. Landrum, and J.P. Giesy. 1983. Anthracene bioconcentration and biotransformation in chironomids: Effects of temperature and concentration. Environmental Pollution 30:175-188.

Hall, K.J., V.K. Gujral, P. Parkinson, and T. Ma. 1984. Selected organic contaminants in fish and sediments from the Fraser River Estuary, British Columbia. Presented at the 11th Annual Aquatic Toxicity Workshop. Vancouver, British Columbia.

Health and Welfare Canada. 1987. Guidelines for Canadian drinking water quality. Federal-Provincial Subcommittee on Drinking Water. Ottawa, Canada. 20 pp.

Hipel, K.W. 1985. Time series analysis in perspective. Water Resources Bulletin 21(4):609-624.

Jensen, K., A. Randlov, and H.U. Riisgard. 1981. Heavy metal pollution from a point source demonstrated by means of mussels (Mytilus edulis). Chemosphere 10:761-765.

Karichkoff, S.W., D.S. Brown, and T.A. Scott. 1979. Sorption of hydrophobic pollutants on natural sediments. Water Research 13:241-248.

Kawamura, K., R. Ishiwatari and M. Yamazaki. 1980. Identification of polyunsaturated fatty acids in surface lacustrine sediments. Chemical Geology 28:31-39.

Kistritz, R.U. 1988. A review of potential biomonitoring organisms and techniques applicable to the Fraser River Estuary. Water Quality Branch. Environment Canada. Vancouver, British Columbia. 42 pp.

Leland, H.V. and J.L. Carter. 1985. Effects of copper on production of periphyton, nitrogen fixation and processing of leaf litter in a Sierra Nevada, California, stream. Freshwater Biology 15:155-173.

Letourneau, J., J. Jasper, and S. Lewis. 1988. NWT interests and needs. Indian and Northern Affairs Canada and the Government of the Northwest Territories. Yellowknife, Northwest Territories. 9 pp.

Lettenmaier, D.P., K.W. Hipel, and A.L. McLeod. 1978. Assessment of environmental impacts. Part two: Data collection. Environmental management 2:537-554.

Louisiana Pacific. 1988. Suitability of life history characteristics for use as a sentinel species. Draft report. 3 pp.

Lynch, T.R., C.J. Popp, and G.Z. Jacobi. 1988. Aquatic insects as environmental monitors of trace metal contamination: Red River, New Mexico. Water, Air, and Soil Pollution 42:19-31.

MacDonald, D.D. 1990. A strategic approach to monitoring ambient environmental quality conditions in the Slave River basin, NWT. Report prepared for Water Resources Division. Indian and Northern Affairs Canada. Yellowknife, Northwest Territories. 60 pp.

MacDonald, D.D. and D. Valiela. 1988. Temporal variability of phosphorus levels in the Flathead River at the international border. Water Pollution Research Journal of Canada 23(4):556-567.

Mah, F.T.S., D.D. MacDonald, S.W. Sheehan, T.M. Tuominen, and D. Valiela. 1989. Dioxins and Furans in Sediment and Fish From the Vicinity of Ten Inland Pulp Mills in British Columbia. Environment Canada. Inland Waters, Pacific and Yukon Region, Vancouver, British Columbia.

Marcheterre, L., G.R.B. Webster, D.C.G. Muir, and N.P. Grift. 1985. Fate of ^{14}C-Octachlorodibenzo-p-dioxin in artificial outdoor ponds. Chemosphere 14(6/7):835-838.

Merriman,, J.C. 1988. Distribution of organic contaminants in water and suspended solids of the Rainy River. Water Pollution Research Journal of Canada 23(4):590-600.

Metcalfe, J.L., M.E. Fox, and J.R. Carey. 1984. Aquatic leeches (Hirudinae) as bioindicators of organic chemical contaminants in freshwater ecosystems. Chemosphere 13:143-150.

Meyers, P.A. and N. Takeuchi. 1979. Fatty acids and hydrocarbons in surficial sediments of Lake Huron. Organic Geochemistry 1:127-138.

Mouvet, C. 1985. Monitoring of polychlorinated biphenyls (PCBs) and hexachlorocyclohexanes (HCH) in freshwater using the aquatic moss Clinclidotus danubicus. The Science of the Total Environment 44:253-267.

Neilson, M. and R. Stevens. 1988. Evaluation of a large-volume extractor for determining trace organic contaminant levels in the Great Lakes. Water Pollution Research Journal of Canada 23(4):578-588.

Newell, A.J., D.W. Johnson, and L.K. Allen. 1987. Niagara River biota contamination project: Fish flesh criteria for piscivorous wildlife. Technical Report 87-3. Division of Fish and Wildlife. Bureau of Environmental Protection. New York State Department for Environmental Conservation. Albany, New York. 182 pp.

Newman, M.C., J.J. Alberts, and V.A. Greenhut. 1985. Geochemical factors complicating the use of aufwuchs to monitor bioaccumulation of arsenic, cadmium, copper, and zinc. Water Research 19:1157-1165.

Oliver, B.G. and A.J. Niimi. 1988. Trophodynamic analysis of polychlorinated biphenyl congeners and other chlorinated hydrocarbons in the Lake Ontario ecosystems. Environmental Science and Technology 22:388-397.

Ongley, E.D. and D.P. Blachford. 1982. Application of continuous-flow centrifugation to contaminant analysis of suspended sediment in fluvial systems. Environmental Technology Letters 3:219-228.

Ongley, E.D., D.A. Birkholz, J.H. Carey, and M.R. Samoiloff. 1988. Is water a relevant sampling medium for toxic chemicals? An alternative environmental sensing strategy. Journal of Environmental Quality 17(3):391-401.

Paasivirta, J., J. Sarkka, K. Surma-Aho, T. Humppi, T. Kuokkanen, and M. Marttinen. 1983. Food chain enrichment of organochlorine compounds and mercury in clean and polluted lakes in Finland. Chemosphere 12(2):239-252.

Remberger, M., A-S. Allard, and A.H. Nielson. 1986. Biotransformations of chloroguaiacols, chlorocatechols, and chloroveratroles in sediments. Applied and Environmental Microbiology 51(3):552-558.

RL&L/EMA Slave River Joint Venture. 1985. Fall fish spawning habitat survey, 1983 -1985. Report prepared for the Slave River Hydro Study Group. Edmonton Alberta. 102 pp & appendices.

Reynoldson, T.B. 1985. The utility of benthic invertebrates in water quality monitoring. Water Quality Bulletin 10:21-28.

Rodier, L. and M.F. Khalil. 1982. Fatty acids in recent sediments in the St. Lawrence Estuary. Estuarine, Coastal, and Shelf Science 15:473-483.

Russell, R.W. and F.A.P.C. Gobas. 1989. Calibration of the freshwater mussel (Elliptio complanata) for quantitative biomonitoring of hexachlorobenzene and octachlorostyrene in aquatic systems. Bulletin of Environmental Contamination and Toxicology 43:576-582.

Say, P.J., J.P. Harding, and B.A. Whitton. 1981. Aquatic mosses as monitors of heavy metal contamination in the River Etherow, Great Britain. Environmental Pollution B2:295-307.

Satsmadjis, J. and F. Voutsinou-Taliadouri. 1983. Mytilus galloprovincialis and Parapenaeus longirostris as bioindicators of heavy metal and organochlorine pollution. Marine Biology 76:115-124.

Schilperoot, J. and S. Groot. 1983. Design and optimization of water quality sampling networks. Presented at the International Symposium on Methods and Instrumentation for the Investigation of Ground Water Systems.

Swackhamer, D.L. and R.A. Hites. 1988. Occurrence and bioaccumulation of organochlorine compounds in fishes from Siskiwit Lake, Isle Royale, Lake Superior. Environmental Science and Technology 22:543-548.

Swain, L.G. and D.G. Walton. 1988. Report on the 1987 benthos and sediment monitoring program. Ministry of Environment and Parks. Victoria, British Columbia. 66 pp.

Tatem, H.E. 1986. Bioaccumulation of polychlorinated biphenyls and metals from contaminated sediment by freshwater prawns (Macrobrachium rosenbergii) and clams (Corbicula fluminea). Archive of Environmental Contamination and Toxicology 15:171-183.

Valiela Ward, D. 1978. Biological environmental impact studies: Theory and methods. Academic Press. 157 pp.

van der Oost, R., H. Heida, and A. Opperhuizen. 1988. Polychlorinated biphenyl congeners in sediments, plankton, mollusks, crustaceans, and eel in a freshwater lake: Implications of using reference chemicals and indicator organisms in bioaccumulation studies. Archives of Environmental Contamination and Toxicology 17:721-729.

Ward, R.C. 1979. Regulatory water quality monitoring: A systems perspective. Water Resources Bulletin 15:369 380.

Ward, R.C., J.C. Loftis, and G.B. McBride. 1986. The 'data-rich but information-poor' syndrome in water quality monitoring. Environmental Management 10(3):291-297.

Water Management Branch. 1989. The attainment of ambient water quality objectives in 1988. British Columbia Ministry of Environment. Victoria, British Columbia. 166 pp.

Wehr, J.D., A. Empain, C. Mouvet, P.J. Say, and B.A. Whitton. 1983. Methods for processing aquatic mosses used as monitors of heavy metals. Water Research 17:985-992.

Whitfield, P.H. 1982. Selecting a method for estimating substance loadings. Water Resources Bulletin 18(2):203-210.

Whitfield, P.H. 1988. Goals and data collection designs for water quality monitoring. Water Resources Bulletin 24(4):775-780.

Whitton, B.A., P.J. Say, and B.P. Jupp. 1982. Accumulation of zinc, cadmium, and lead by the aquatic liverwort Scapania. Environmental Pollution B3:299-316.

Wren, C.D., H.R. MacCrimmon, and B. Loescher. 1983. Examination of biomagnification and bioaccumulation of metals in a freshwater system. Water, Air, and Soil Pollution 19:277-292.

Wren, C.D. and H.R. MacCrimmon. 1986. Comparative bioaccumulation of mercury in two adjacent freshwater ecosystems. Water Research 20(6):763-769.

Yaksich, S.M. and F.H. Verhoff. 1983. Sampling strategy for river pollutant export. Journal of the Environmental Engineering Division of the American Society of Civil Engineers 109:219-231.